Buyer aversion to flood-resistant homes*

Hannah Druckenmiller[1,2,3], Jaimie Choi[4], and Billy Babis[5]

[1]California Institute of Technology
[2]National Bureau of Economic Research
[3]Resources for the Future
[4]Duke University
[5]Stockholm Environment Institute

PRELIMINARY DRAFT: Please do not cite or distribute.

Abstract

We examine the "adaptation puzzle" — where individuals underinvest in cost-effective climate resilience — through the lens of flood-resistant building codes in the United States. Linking novel data on community-level flood code adoption with property-level real estate and flood data, we assess whether elevated homes reduce flood damages and whether these expected savings capitalize into home values. We find that while each additional foot of elevation reduces flood damage by 1.8% of property value, it also lowers home prices by 3%. This negative valuation is reversed in the wake of a recent flood, a pattern that appears to be driven by lower damages among elevated homes rather than increased salience of flood risk. Finally, we show that buyer aversion to elevated homes is most likely explained by unaccounted for inconvenience costs, suggesting that lack of adoption may be economically rational. Our findings underscore the challenges of adapting capital assets to growing climate risks.

*We thank Margaret Walls, Yanjun (Penny) Liao, Christopher Timmins, and seminar participants at TWEEDS and UCSB for helpful comments and suggestions. This research was in part funded by individual gift to Resources for the Future from Mr. Kenan Sahin; we are grateful for his support.

1 Introduction

Homes are often the most valuable asset that American households own, yet are increasingly at risk from natural disasters. By one estimate, 14.5 million homes, or nearly one in every ten, are affected by a natural disaster each year (Corelogic 2022). Indeed, over the past fifty years, the United States has sustained more than $2 trillion in property damage due to such events (Bhola et al. 2023). This risk is only increasing, driven by a combination of climate change — which is intensifying the frequency and severity of extreme weather – and the continued development of housing in hazard-prone areas. Despite growing risks, homeowners often underinvest in seemingly cost-effective measures to protect their homes. This failure to adopt available and financially sensible disaster resilience measures is known as the "adaptation puzzle" (Dolšak and Prakash 2018). Why do homeowners choose not to safeguard what is likely their most important capital asset?

This paper investigates the adaptation puzzle through the lens of hazard-resistant building codes in the United States. These codes establish minimum construction standards intended to reduce the risk of property damage during natural disasters. Although hazard-resistant building standards are widely recognized as a key adaptation tool in the face of climate change, these building practices have failed to proliferate based on market forces alone. Further, many jurisdictions do not adopt and enforce federally recommended standards. As of 2020, the Federal Emergency Management Agency (FEMA) reported that 65% of counties, cities, and towns had not implemented modern hazard-resistant building codes (FEMA 2020b).

We focus on the adoption and effectiveness of flood-resistant building codes, with a particular emphasis on "freeboard" requirements — regulations that mandate elevating a building's lowest floor above the base flood elevation. Flooding is the most frequent and costly natural hazard in the United States, responsible for average annual damages exceeding $32 billion — a figure projected to surpass $40 billion by 2050 (Wing, Lehman, et al. 2022). Flood codes aim to reduce these damages through building standards such as minimum elevation requirements, the use of water-resistant materials, and the integration of breakaway walls (FEMA 2018). While freeboard is widely viewed as the most effective flood mitigation measure, it is also among the most expensive (FEMA 2020a).

We address two primary empirical questions. First, do homes with freeboard command a price premium in the housing market? If elevating a home reduces flood-related losses, then the expected savings on either flood insurance premiums or future property damage should, in theory, be capitalized into higher property values. However, previous research on flood insurance and risk perception suggests that homeowners often underestimate the cost of flooding, even when provided with clear risk information (e.g., Kousky and Michel-Kerjan 2017; Bakkensen and Barrage 2022; Hino and Burke 2021; Wagner 2022). Moreover, any perceived benefits from reduced flood risk may be tempered by buyer aversion to elevated homes. This aversion could

stem from aesthetic preferences or practical concerns, such as the inconvenience of stairs for elderly household members. As a result, it is unclear a priori whether homebuyers are willing to pay more for homes with freeboard, or whether such features are discounted in the market.

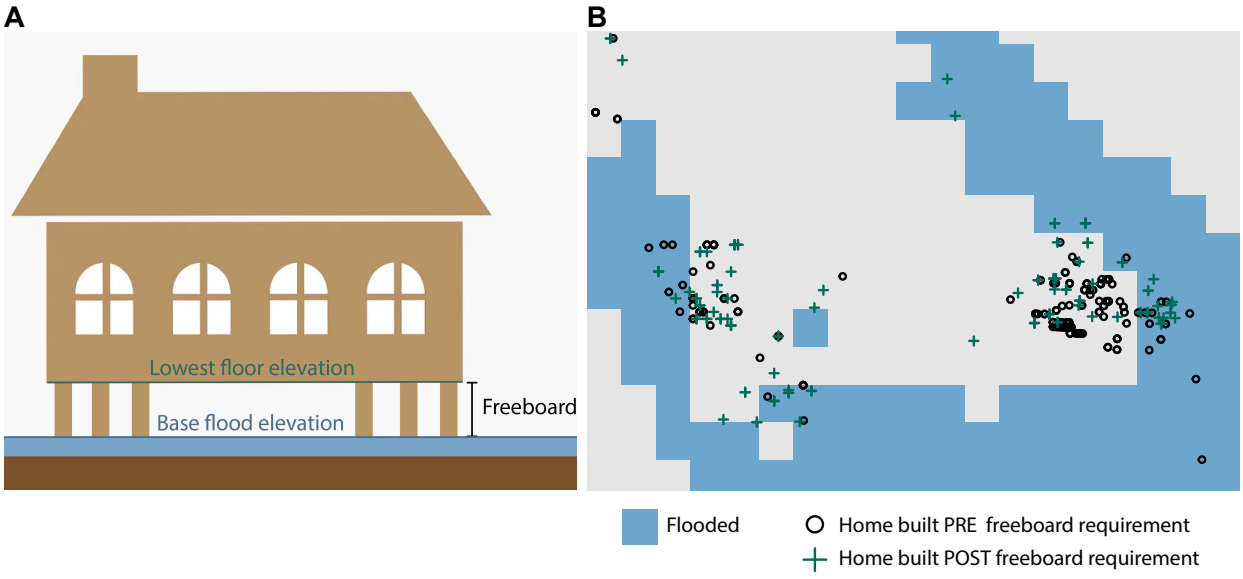
Second, we examine whether freeboard actually delivers financial benefits to homeowners when a flood occurs. Homebuyers may be reluctant to support or comply with flood-resistant building codes if these measures fail to generate meaningful reductions in disaster-related losses. To test this, we quantify the protective value of freeboard by comparing observed flood damages between homes built with and without freeboard requirements. This analysis allows us to assess whether the investment in elevated construction yields measurable returns for buyers.

Our study aims to identify the causal effect of flood-resistant building codes on real estate market outcomes. A key empirical challenge is that the adoption of freeboard requirements is not randomly distributed across states or communities. In particular, areas with greater flood risk are more likely to implement these codes, which introduces potential confounding when estimating their impact on housing markets. To address this issue, we leverage three distinct sources of variation in code exposure to isolate causal effects: (1) spatial and temporal differences in the timing of freeboard adoption, (2) variation in code applicability due to the fact that codes only apply to newly constructed homes, and (3) heterogeneity in flood exposure. Figure 1B illustrates two of these sources of variation using data from Big Pine Key, Florida.

Our empirical estimates are intended to complement prior simulation-based analyses from engineering and disaster mitigation models. For example, a 2020 national study by FEMA evaluated the effectiveness of hazard-resistant building codes in reducing physical damage to buildings and their contents. The study estimated annual savings of $1.6 billion from such codes, with freeboard alone accounting for $484 million in avoided damages. Importantly, the additional cost of incorporating hazard-resistant features into new construction is relatively modest—on average, less than 2% of total construction costs, according to the National Institute of Building Sciences (Porter et al. 2019). These findings have led FEMA to conclude that "one of the most cost-effective ways to safeguard our communities against natural disasters is to adopt and follow hazard-resistant building codes" (FEMA 2020b).

We make two primary contributions to the literature. To our knowledge, we provide the first nationally representative estimates of homebuyers' willingness to pay for flood-resistant housing. Although FEMA projects that freeboard requirements generate substantial monetary benefits at relatively low cost, market forces alone have not driven widespread proliferation of elevated homes. Understanding this disconnect requires quantifying the value that buyers place on flood-resistant homes and comparing that value to the incremental costs of construction. Empirical evidence on this question remains limited. The most closely related studies—Dumm, Sirmans, and Smersh 2011 and Ostriker and Russo 2024—offer mixed findings.

Figure 1: Illustration of freeboard requirements



Notes: Panel A depicts freeboard, which is defined as the additional height requirement for the lowest floor elevation of a home above base flood elevation. Base flood elevation is the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year. Panel B shows an example of the data used in the empirical analysis in Big Pine Key, Florida. The map shows areas that were flooded (blue), overlaid with property sales. Homes that were built prior to any freeboard requirements are shown by black circles. Homes that were built after freeboard requirements were adopted are shown by green crosses.

Dumm, Sirmans, and Smersh 2011 report that the stricter 1994 South Florida Building Code significantly increased property values in Miami-Dade County, particularly in high-risk coastal areas. In contrast, Ostriker and Russo 2024 find no significant change in housing prices following the adoption of flood-resistant standards in Florida communities.

We also contribute some of the first empirical evidence on the realized flood mitigation benefits of building codes. While engineering models consistently predict large reductions in damage from hazard-resistant codes, few data-driven studies validate these projections (Czajkowski, Simmons, and Done 2017). If actual savings fall short of expectations, the cost-effectiveness of these building practices may be overstated. Such a "performance gap" between projected and realized savings is well documented in other policy areas, including energy efficiency programs (e.g., Levinson 2016; Fowlie, Greenstone, and Wolfram 2018). In the context of flood mitigation, several factors may contribute to underperformance: weak code enforcement, noncompliance or poor implementation by homeowners and builders due to cost concerns (Vaughan and Turner 2013), and the potential that even well-executed construction fails under extreme events beyond design specifications (Deryugina 2013).

We have three main findings. First, freeboard is strongly associated with reduced damages from flooding.

Each additional foot of elevation is associated with a reduction in flood losses equivalent to 1.8% of the property's total value. However, our empirical estimates of the impact of freeboard on flood losses exhibit important differences from estimates derived from simulation-based approaches.

Second, despite these protective benefits and discounts on flood insurance premiums for elevated homes, we find that homebuyers, on average, exhibit negative willingness to pay for homes with freeboard. Each additional foot of freeboard reduces a home's market value by approximately 3%, or about $10,000 for the average property in our sample. This price discount appears to reflect a general distaste for elevated construction, which is particularly pronounced in communities with larger elderly populations, suggesting that concerns about accessibility may be a key driver of buyer aversion.

Third, recent flood experience increases demand for elevated homes, particularly in inland floodplain areas. This shift appears to be driven primarily by the lower flood damages among elevated homes, rather than by increased salience of flood risk. Specifically, we find no evidence that near-miss flood events — those that impact the broader community but not the transacted property — increase willingness to pay for freeboard.

Our findings have important implications for the design of natural disaster adaptation policies. As climate change accelerates the frequency and severity of extreme weather events and development continues in disaster-prone areas, promoting resilience has become a policy priority. While recent federal initiatives have encouraged the integration of hazard mitigation principles into local planning and development, the adoption of recommended resilience strategies remains limited. Our results help explain this adaptation puzzle by identifying a specific barrier – the inconvenience cost of flood-resistant construction. Indeed, our findings suggest that lack of widespread adoption may be economically rational. Thus changes in design practices may be required to increase the resilience of the housing stock to increasing flood risk under climate change.

2 Illustrative model

We begin with a simple model that illustrates a representative buyer's decision to purchase a home with freeboard. The model incorporates three key components: (i) expected reduction in flood-related property damage, if the home is uninsured, (ii) reduction in flood insurance premiums, if the home is insured; and, (iii) any convenience costs or benefits associated with freeboard. Let the buyer's home valuation (V) be given by

$$V(F, I) = B - \mathbb{1}[I = 1]\alpha(1 - \delta F) - \mathbb{1}[I = 0]\pi D(F) - C(F) \tag{1}$$

where B is the baseline value of the home, excluding flood-related considerations. The term $F \in \{0, 1\}$ is an indicator for whether the home has freeboard and $I \in \{0, 1\}$ is an indicator for whether the home is insured against flooding.

We define α as the net present value of annual flood insurance premiums for a non-elevated home. We assume that insurance premiums are discounted for homes with freeboard. For simplicity, we model this as a proportional discount using the term δ. Thus, for insured homes, the term $\mathbb{1}[I = 1]\alpha(1 - \delta F)$ captures the capitalization of reduced flood insurance premiums into the home's value.

For uninsured homes, insurance premiums are not relevant, but the buyer considers the expected cost of future floods, which we model using the term $\mathbb{1}[I = 0]\pi D(F)$. Here, we define π as the buyer's subjective probability of a flood occurring. If a flood does occur, the homeowner assumes expected damage of $D(F)$, where $D(1) < D(0)$.

Finally, $C(F)$ denotes the convenience cost freeboard. We choose to model this as a cost, such that a positive value of $C(F)$ corresponds to a reduction in home value. Note, however, that this term could be positive (e.g. accessibility concerns presented by freeboard would reduce home value) or negative (e.g., reduced nuisance costs of flooding would increase home value).

Let the marginal value of freeboard be $\Delta V = V(1, I) - V(0, I)$. Using equation 1, we can write the marginal value of freeboard as

$$\Delta V = \mathbb{1}[I = 1]\alpha\delta + \mathbb{1}[I = 0]\pi[D(0) - D(1)] - C(1) \tag{2}$$

The first term, $\mathbb{1}[I = 1]\alpha\delta$, represents the insurance savings for homes with freeboard. The second term, $\mathbb{1}[I = 0]\pi[D(0) - D(1)]$, represents the expected avoided damages when uninsured. The third term $C(1)$ reflects the convenience cost freeboard. While the first two terms are expected to have a positive sign (increase the home's valuation), the sign of the third term is unknown.

The impact of freeboard on home values is thus theoretically ambiguous. If the insurance savings or damage avoidance exceeds the convenience cost, homes with freeboard will command a price premium ($\Delta V > 0$). If the convenience cost dominates, homes with freeboard will sell at a discount ($\Delta V < 0$). If buyers' valuation is negative, it may suggest that the decision not to adopt freeboard is welfare-increasing. Indeed, so long as the inconvenience cost of freeboard $C(F)$ is sufficiently large, ΔV may be negative even if insurance premiums are actuarily fair (i.e., α and δ are well calibrated) and buyers' have accurate perceptions of flood risk π and expected damages $D(F)$. However, it is also possible that $\Delta V < 0$ only because flood insurance premiums are subsidized and/or homeowners have incorrect perceptions of flood risk. In this case, interventions to increase freeboard adoption may be required.

To unpack this puzzle, this paper empirically estimates the different components of this illustrative model. First, we examine the relationship between freeboard and flood insurance premiums using policy-level data from the National Flood Insurance Program (NFIP). Second, we assess to what extent freeboard reduces damages from flooding using claims-level data from the NFIP. Third, we estimate ΔV using transaction-level data on residential homes sales from CoreLogic. Finally, we attempt to isolate the inconvenience cost of flooding through a case study of short-term rentals, where renters should consider convenience of different housing options, but not their long-term flood risk or flood insurance premiums.

3 Empirics

3.1 Data

Our analysis links community-level information on freeboard adoption with parcel-level data on home values, historical flood exposure, and damages from flooding. Below, we briefly describe each data source. Additional details on data construction are provided in Appendix A.1.

Adoption of flood-resistant codes. We compile data on freeboard adoption at the community-by-flood zone level for more than 22,000 communities across the United States.[1] Our freeboard adoption statistics are primarily based on the Federal Emergency Management Agency's (FEMA) nationwide Freeboard Database, which the agency compiled for their 2020 *Building Codes Save* study (FEMA 2020a). Our team supplemented these data in communities with missing or outdated information using state-level building code requirements and conversations with local officials.

Flood damages. We measure damages from flooding using claims from the National Flood Insurance Program (NFIP). The NFIP is the dominant insurer for flooding in the United States. As of January 2023, over 22,000 communities in all 50 states participated in the NFIP, with nearly 5 million policies providing almost $1.3 trillion in coverage (Congressional Research Service, 2023). FEMA makes redacted NFIP claims data publicly available. These data include the amount paid for damage to the building and its contents, the date of the flood, and the water depth. These data also include information on the property's freeboard height, its total value, its year of construction, its flood zone, and its base flood elevation. While the address of the property is redacted, the data includes the property's census tract and NFIP community.

Property sales. We use information on property sales and values from Corelogic. Corelogic is the country's largest real estate database and includes more than 400 million detailed public records across over 2,750 U.S.

[1] Throughout the paper, we define communities following the National Flood Insurance Program (NFIP). Specifically, communities are jurisdictions with the ability to implement floodplain management policies. Communities range from cities to counties.

counties. We limit our sample to residential properties constructed after 2000 – the first year for which we can observe freeboard requirements. Corelogic provides the sales price and date for each transaction, approximate coordinates identifying the location of the property, and a wide range of other property characteristics, such as lot size and number of bedrooms.

Flood risk. We identify the flood risk of each parcel by intersecting the property coordinates of each Corelogic transaction with the National Flood Hazard Layer (NFHL). The NFHL provides detailed digital maps for twelve types of flood zones, ranging from areas of minimal flood risk (Zone X, for example) to areas with 1% of greater annual chance of flooding (Zones A and V, for example). Areas with at least 1% annual chance of flooding are defined by FEMA as Special Flood Hazard Areas (SFHA) and are often subject to more stringent flood-related regulations, such as stricter flood codes and the requirement to purchase flood insurance in order to qualify for a federally backed mortgage.

Flood exposure. We use flood inundation maps from the Global Flood Database (GFD) (Tellman et al. 2021) to measure historical flood exposure. The GFD provides flood inundation maps for 110 large regional floods in the United States between 2001 and 2018, allowing us to observe flooding at the property level. These data were constructed using information on the dates and approximate locations of floods from the Dartmouth Flood Observatory in combination with daily satellite imagery at 250-meter resolution from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) to estimate flood extent. Example inundation maps for three events from the database are shown in Figure A2.

3.2 Flood damages model

We first estimate the relationship between freeboard and property damages from flooding. For this part of the analysis, we use data from the NFIP, which provides both property-level information on freeboard height and a direct measure of damages from flooding: payouts on flood insurance claims. We model the relationship between freeboard height and flood damages using the equation:

$$damage_{ijczy} = \alpha freeboard_i + \beta BFE_i + \gamma_j + \lambda_c + \omega_z + \delta_y + \epsilon_{ijczy} \tag{3}$$

where the dependent variable *damage* is either measured as relative damage (damage/structure value) or log NFIP payouts. Here, i indexes the individual flood insurance claim, j indexes community, z indexes flood zone, c indexes the property's year of construction, and y indexes the year of loss. The treatment variable, $freeboard$, measures the freeboard height of the property, defined as the difference in elevation (in feet) between base flood elevation and the lowest floor of the structure. We control for for base flood

elevation (BFE_i) to account for property-level flood risk. We also include community fixed effects (γ_j) to account for time-invariant differences in flood insurance claims across communities, year of construction fixed effects (λ_c) to account for differences in building practices over time, flood zone fixed effects (ω_z) to account for differences in claims across FEMA-rated flood zones, and year of loss fixed effects (δ_y) to account for differences in NFIP payouts across years. Standard errors are clustered at the state level to account for spatial correlation in the error terms over both time and space.

In addition to the baseline specification described in Equation (3), we estimate two alternative specifications. First, we allow for a non-linear relationship between freeboard height and flood damages by including bins of freeboard height in increments of one foot as explanatory variables. Second, we allow for differential benefits of freeboard height by flood depth by interacting an indicator for freeboard with a claim-level measure of water depth. Estimating equations for these two extensions are provided in Appendix A.2.

Importantly, our analysis of the impact of freeboard height on flood damages is largely descriptive; we do not have exogenous variation in freeboard height across NFIP properties. The next section focuses on establishing the causal effect of freeboard code adoption on housing market outcomes, which is a key relationship for informing policy-making.

3.3 Home values model

The second part of our analysis aims to identify the effect of freeboard requirements on home values. A key challenge to estimation is that freeboard adoption is not randomly assigned across states and communities . If communities with higher flood risk are more likely to adopt freeboard requirements, this could confound our estimated effects of the housing market impacts of more stringent flood codes. To overcome this challenge, we exploit three different sources of variation in building code treatment status across homes to establish causal effects: spatial and temporal variation in freeboard adoption status, variation in freeboard applicability by home vintage (since requirements only apply to new construction), and variation in flood exposure.

We have two primary empirical questions. First, do homes with freeboard command a higher price? Second, to what extent does freeboard pay off for buyers in the event of a flood? We take these questions to the data using property-level information on home values and historical flood exposure in combination with community-by-flood zone level information on freeboard height requirements.

Critically for our empirical design, freeboard requirements only apply to homes constructed *after* adoption. Intuitively, our estimation strategy compares property sales prices within the same community-year-month for homes that were constructed before and after freeboard requirements were adopted, while using properties in communities without freeboard requirements to control for the confounding effect of year of

construction. This concept is illustrated in Figure 1B, which shows a flood inundation map (blue), overlaid with property sales that occurred in the year after the flood. Black circles show properties that were constructed before the adoption of freeboard requirements and red dots show properties that were constructed after freeboard requirements were adopted. The plot illustrates two of the sources of variation we are using in estimation: variation in building code applicability by home vintage and property-level variation in whether the home was flooded.

We estimate the housing market impacts of the freeboard height using the equation:

$$\begin{aligned} ln(price_{ictjszy}) = \alpha Freeboard_{jzc} + \beta(Flooded_{iy} \times Freeboard_{jzc}) + \gamma Flooded_{iy} \\ + \zeta \mathbf{X_i} + \lambda_c + \theta_t + \mu_{jz} + \delta_{jy} + \epsilon_{ictjzy} \end{aligned} \tag{4}$$

where the dependent variable $ln(price_{iczjt})$ denotes the log sales price of property i, constructed in year c, located in census tract t, community j, and flood zone z, and sold in year-month y. $Flooded_{iy}$ is a parcel-level indicator variable for whether the property was flooded in the year preceding the sale, as measured using flood inundation maps from the Global Flood Database. $Freeboard_{jzc}$ denotes freeboard requirements, in feet, for the home's community and flood zone at the time of construction. The parameter α, identifies willingness to pay for flood-resistant codes in the absence of a recent flood. The parameter β identifies the price premium for homes built with freeboard after a recent flood. The effect of a recent flood on the sales prices of properties without freeboard is captured by γ.

Equation 9 contains a vector of property-level controls ($\mathbf{X_i}$) for lot size, distance to the central business district, distance to shoreline[2], and distance to riverine. We also include a control that proxies for property-level flood risk: the interaction between a count of the total number of times the property was flooded according to the Global Flood Database and the FEMA Special Flood Hazard Area (SFHA).[3] The equation also includes year-of-construction fixed effects (λ_c) to account for differences in home values and flood-resistance by home vintage, census tract (θ_t) and community-by-flood zone fixed effects (μ_{jz}) to account for time-invariant differences in home values across locations, and community-by-year-month fixed effects δ_{jy} to account for location-specific time trends in property values unrelated to flood codes. The error term ϵ_{ictjzy} captures unexplained variations. We cluster standard errors at the state level to account for correlation in error terms over both time and space.

[2]For computation reasons, distance to shoreline is modelled in discrete-continuous fashion. $\mathbf{X_i}$ contains binary control for whether the property is located in a shoreline state interacted with a variable measuring distance to shoreline, which is set to zero in non-shoreline states.

[3]SFHA are FEMA flood zones beginning with the letter "A", which have a greater than 1% chance of annual flooding and zones beginning with the letter "V", which are coastal zones with a greater than 1% chance of annual flooding and an additional hazard associated with storm-waves.

We expand on our baseline specification described in Equation (9) in a four ways (see Appendix A.2 for details). First, we estimate an event study version of this equation that includes leads and lags of flood indicators interacted with the *Freeboard* treatment variable. The event study serves two purposes. First, allows us to test for pre-trends in freeboard valuations; since we assume the timing of a flood is random, there should be no effect of future floods on freeboard values. Second, it allows us to characterize the temporal relationship between freeboard and past floods. That is, we can estimate how long ago a flood has to be to no longer impact freeboard valuations.

Second, we test for one reason why home buyers may have a distaste for freeboard: difficulty accessing the homes. Intuitively, we expect elevated homes to be more inconvenient for older Americans for whom accessibility is a larger concern. We therefore test whether willingness to pay for freeboard requirements is lower in locations with a greater share of people over the age of 65. In practice, we implement this test by interacting *Freeboard* with the share of households with at least one 65+ year old individual for each census tract according to the 2010 decennial census.

Third, we want to understand *why* a recent flood affects homebuyer's valuation of freeboard height. It is possible that this difference is simply explained by lower property damages to homes with freeboard in the event of a flood. However, a recent flood could also affect freeboard valuation by increasing information about and/or salience of local flood risk (Gallagher 2014). We test to what extent salience of flood risk contributes to the price premium by estimating the effect of freeboard height on property values for homes that were not themselves flooded, but which are located in communities that were recently flooded (hereafter referred to as a "near-miss"). We estimate the effect of a near-miss by including an additional treatment variable in Equation 9: an indicator for the community being hit by at least one flood in the past year interacted with freeboard height. The parameter estimate for this variable describes the price effect of a recent flood in the community that did not inundate the property. Such a near-miss would not result in any property damage to the home, but could increase information about and/or salience of local flood risk.

Fourth, we probe to what extent compliance with community-level freeboard requirements affects our estimates. Importantly, in the part of the analysis focusing on property value impacts, we do not observe property-level freeboard heights; we only observe freeboard requirements at the community-level. Based on data from the NFIP, we estimate that about 85% of homes with flood insurance policies are compliant with community-level freeboard requirements (among those homes constructed after freeboard adoption). However, some communities have far lower levels of compliance (Figure A3). We test whether the price impacts of freeboard depend on compliance by interacting our treatment variables with an estimate of the share of compliant homes in the community. We construct this estimate using the NFIP policies database for all communities with at least 10 claims over the study period. This sample of communities includes 52%

of the property transactions in our sample (5.9 million of 11.3 million), but accounts for 68% damages from flooding in the US, as measured by NFIP claims.

Finally, we divide the data into coastal communities and inland communities to account for differential flood severity and salience of flood risk across these two areas. Specifically, whereas inland floods result from excessive precipitation, coastal floods arise from high tides, which are exacerbated when paired with heavy onshore wind and rainfall. Moreover, living on the coast may make flood risk more salient to homebuyers. We estimate the same Equation 9 on these subsamples to assess how proximity to the coast affects property damages from flooding and homebuyers' valuation of freeboard before and after flood events.

4 Results

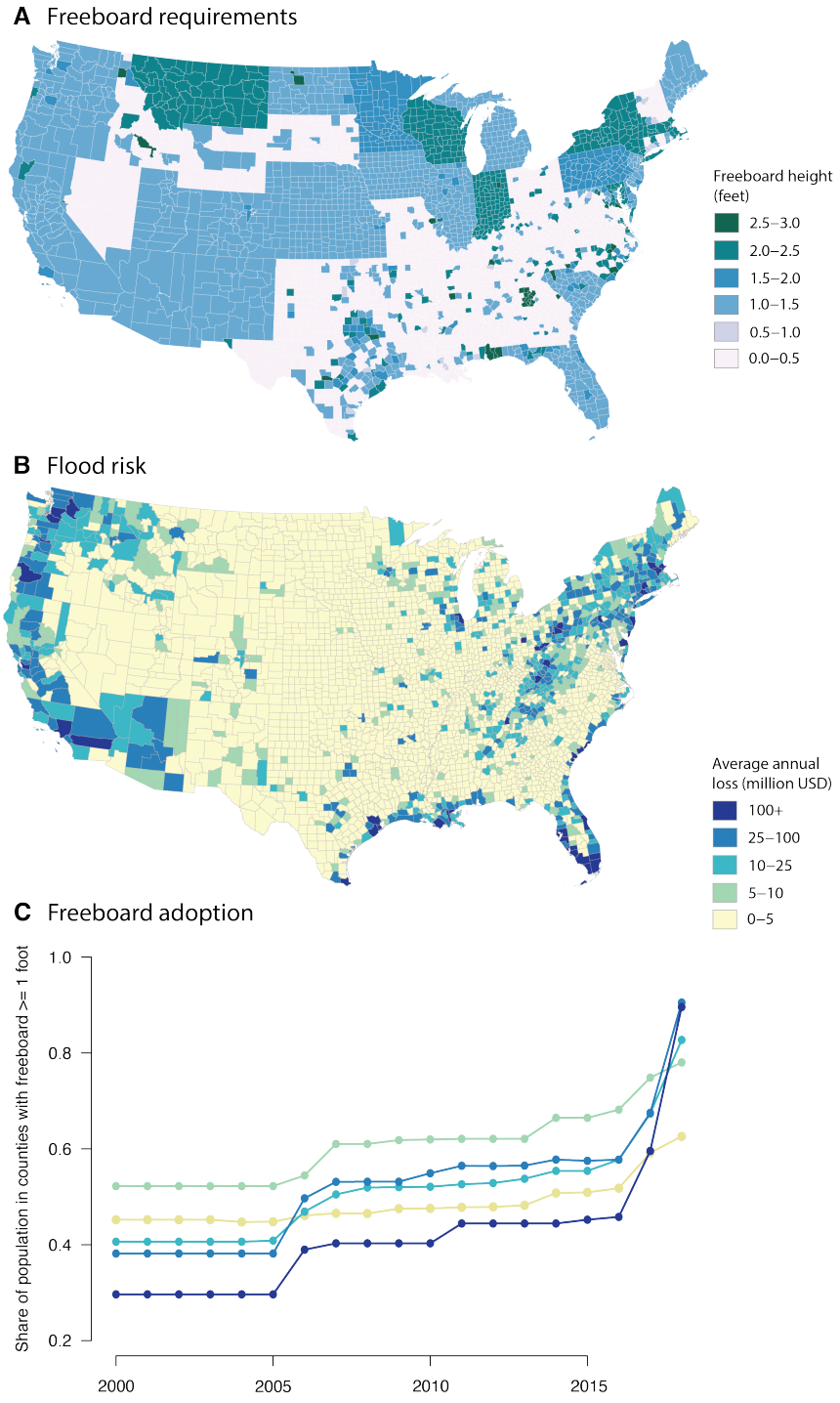
Please note: This paper is still in progress and the current draft is missing some of the components of the paper outlined in the introduction. We are confident that we will have all of the components completed by September, 2025.

4.1 Freeboard Adoption

Adoption of flood-resistant codes can occur at the state or local level. In 2018, 19 states had freeboard requirements of one foot, two states (Minnesota and Pennsylvania) had freeboard requirements of one and a half feet, and five states (Indiana, Massachusetts, Montana, New York, and Wisconsin) had freeboard requirements of two feet. However, many communities elect to adopt more stringent requirements than is required by the state (Figure 2 Panel A). For example, although Texas and Georgia have no state-level freeboard requirement, several communities in these states have freeboard requirements of two or more feet.

The adoption of flood-resistant codes is strongly correlated with flood risk (Figure 2 Panel B). Among locations with $100 million or more in annual losses from flooding, 90% of the population live in counties with freeboard requirements of at least one foot. However, the alignment between flood risk and freeboard height requirements is fairly recent (Figure 2 Panel C). In 2000, less than 30% of the population living in high risk areas resided in counties with freeboard height requirements of at least one foot. In fact, freeboard adoption remained relatively low in these high risk locations until 2017. Code adoption is also correlated with population characteristics; freeboard requirements are increasing in home prices, population density, and the share of democratic voters (Figure A1).

FIGURE 2: FREEBOARD HEIGHT REQUIREMENTS AND FLOOD RISK



Notes: Panel A shows freeboard height requirements, by county, in 2018. Native data on freeboard height requirements are at the NFIP community level and is aggregated to the county-level for display purposes using population weights. Panel B depicts flood risk, by county, measured in average annual losses. Data are from Wing, Lehman, et al. 2022. Panel C graphs freeboard adoption over time by level of flood risk.

4.2 Flood damages

We find that freeboard height is strongly associated with reductions in damages from flooding. Table 1 shows that for each additional foot of freeboard, relative damage (damage/structure value) decreases by 1.8 percentage points (95% CI = 1.2 to 2.4 pp) and NFIP payouts decrease by 12.2% (95% CI = 8.2 to 16.2%). To provide a sense of magnitude, the mean value of a home in our sample is approximately $308,000 and the mean value of an NFIP claim is $63,000, so these estimates equate to a reduction in flood damages in the range of $5,400 to $7,700. Columns 2 and 4 repeat the analysis using a non-linear specification of freeboard. We find that flood damages decrease monotonically with freeboard height. Our estimates in Column 2 suggest that relative damage is 3.3 percentage points lower for homes with one foot of freeboard, 4.9 percentage points lower for homes with two feet of freeboard, 6.6 percentage points lower for homes with three feet of freeboard, and 7.1 percentage points lower for homes with four feet of freeboard. Similarly, the decrease in flood damages looks approximately linear when we measure damages in terms of NFIP payouts in Column 4.

We find economically large and statistically significant impacts of freeboard requirements across all flood depths. Figure 3 plots relative damage from flooding as a function of flood depth. The depth-damage function for homes without freeboard is shown in blue. The same relationship for homes with freeboard of at least one foot is shown in green. The black line shows the difference between damages to homes with freeboard and without freeboard. The histogram below the plot shows the distribution of water depths across NFIP claims. When allowing for differential damages by flood depth, we estimate that freeboard requirements reduce relative damage by 5.4 to 11.0 percentage points, with an average of 6.5 percentage points (95% CI = 4.1 to 8.9) or approximately $4,270.

We next compare our empirical estimates of savings from freeboard to the simulated savings produced in FEMA 2020a. FEMA modeled savings from freeboard requirements for the average structure by assuming a one foot difference in flood depths across homes with and without freeboard requirements, simulating flooding using the Hazus Flood User-Defined Facility (UDF) model, and then applying assumed depth-damage functions. Using this procedure, FEMA estimates that freeboard saves the average structure approximately $1,500 in annualized average losses, or approximately $9,700 in the event of a flood. Our estimates of reduced flood damages from one foot of freeboard are 40-80% of this magnitude, suggesting that realized savings may fall short of simulated savings.

There are at least two reasons why simulated and observed savings are not well aligned. For one, Wing, Pinter, et al. 2020 show that FEMA depth-damage functions do not fit the data well; damage associated with NFIPS claims is better predicted by the mean observed damage than federal depth-damage functions.

Table 1: Effect of freeboard height on flood damages

	Dependent variable:			
	Relative damage		Log NFIP claims	
	(1)	(2)	(3)	(4)
Freeboard (feet)	-0.018^{***}		-0.122^{***}	
	(0.003)		(0.020)	
Freeboard = 1 foot		-0.033^{***}		-0.216^{***}
		(0.007)		(0.046)
Freeboard = 2 feet		-0.049^{***}		-0.321^{***}
		(0.007)		(0.055)
Freeboard = 3 feet		-0.066^{***}		-0.401^{***}
		(0.010)		(0.063)
Freeboard = 4+ feet		-0.071^{***}		-0.504^{***}
		(0.012)		(0.084)
Observations	95,553	95,553	95,553	95,553

Notes: We estimate the impact of freeboard on damages from flooding using Equation (3) and data from the National Flood Insurance Program (NFIP) Redacted Claims Dataset. The dependent variable in columns (1) and (2) is relative damage, defined as flood damages divided by total property value. Flood damages are measured as payouts on NFIP claims. The mean property value in the sample is $209,281. The dependent variable in columns (3) and (4) is log NFIP claims. The mean NFIP claim in the sample is $63,275. Standard errors are clustered by county. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.

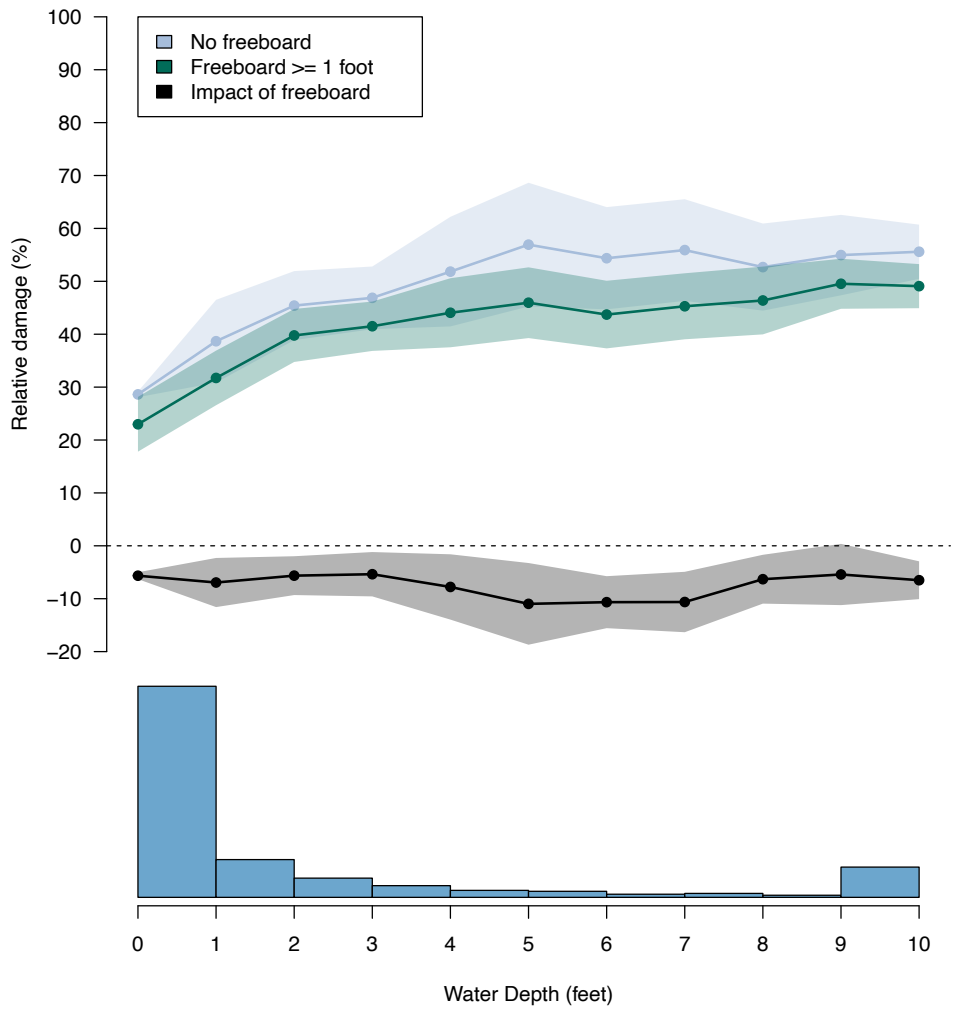
Additionally, Figure 3 shows that freeboard of a given height is not equivalent to reducing flood depth by that height. For example, the FEMA model assumes no damage to homes with freeboard requirements that equal or exceed the recorded flood depth, but Figure 3 suggests that there is still significant amounts of property damage in such scenarios.

How do our estimated savings compare with the cost of complying with freeboard requirements? FEMA approximates that the up-front costs of building a home with freeboard are 0.25 to 1.5% of the total construction costs for each foot of freeboard (FEMA n.d.). For the average new home in the United States, this suggests an upfront cost of $700 to $4,300 per foot of freeboard.[4] The expected savings from freeboard thus match or exceed the expected upfront cost.[5] While savings only occur if and when the home is flooded, we calculate that 93% of census tracts in the US were hit by a flood (had at least one NFIP claim) between 2000 and 2020.

[4]The average cost of building a new home in 2022 was $286,000.

[5]In order to do a full cost-benefit comparison, home buyers would also need to take into account the price of flood insurance premiums. Significant discounts are available for homes with freeboard. For example, one foot of freeboard can result in discounts of approximately 30% on NFIP premiums in high risk flood zones, which typically have costs in the range of $1,500 to $8,500 per year for full coverage on a $250,000 home with $100,000 in contents.

Figure 3: Depth-damage functions by freeboard status



Notes: We estimate relative damage, defined flood damage divided by total property value, as a function of flood depth. The top panel shows the estimated depth-damage function for homes without freeboard (light blue) and with freeboard (dark green). The black line shows the difference in relative damage, at each flood depth, by freeboard status. Polygons show 95% confidence intervals. Data come from the National Flood Insurance Program's Redacted Claims Dataset.

4.3 Housing market impacts

We next examine the impact of freeboard height on housing market outcomes. Table 3 column 1 shows the results of our baseline specification from Equation 9 in the full sample of US homes constructed after the year 2000. The first row shows that in the absence of a recent flood, each additional foot of freeboard reduces home values by 3.1%. That is, home buyers have negative willingness to pay for elevated homes. To provide a sense of scale, the average sales price for a home in our sample is $308,000, so each foot of freeboard is associated with approximately $10,000 less in value. This negative willingness to pay for freeboard may reflect a lack of information about the monetary savings associated with freeboard or a strong

Table 2: Effect of freeboard requirements on property values: Subset Data

	Dependent variable: Log property sale price		
	(1) Full Sample	(2) Coastal Sample	(3) Inland Sample
Freeboard	-0.0310**	-0.0263**	-0.0227**
	(0.0131)	(0.0127)	(0.0104)
Flooded	-0.0278**	-0.0315**	-0.0185
	(0.0111)	(0.0140)	(0.0208)
Freeboard × Flooded	0.0840***	0.0624**	0.2497***
	(0.0243)	(0.0282)	(0.0486)
Linear combinations of coefficients			
Freeboard + Freeboard × Flooded	0.0530**	0.0361	0.2270***
	(0.0235)	(0.0260)	(0.0515)
Observations	11,307,977	5,679,758	5,628,219

Notes: We estimate the effect of home values at the property-level in areas with different locational attributes. Coastal are properties that are within 50 miles of the coast. Inland are properties that are beyond the 50 miles. Results are robust to dividing properties based on a 25 mile distance. All regression specification follow Equation (9). Standard errors are clustered by state. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.

distaste for elevated homes that outweighs expected savings. Columns 2 and 3 of Table 2 show the estimates separately for coastal communities and inland communities, respectively. Our estimates of willingness to pay for freeboard are similar in both coastal and inland areas.

The second row of Table 3 shows the price discount associated with a recent flood. In the full sample, we estimate that a flood in the last 12 months reduces property values by 2.8%, or $8,500 for the average home in our sample. The effect size is larger in coastal communities (3.2%) and smaller in inland communities (1.9%). Using these estimates, we calculate that our sample of post-2000 construction, property damages attributable to the 110 large regional floods we study total to $788 million.

Finally, the third row of Table 3 shows the differential effect of freeboard in the wake of a recent flood. We find that a flood in the last 12 months flips homewowners' willingness to pay for freeboard from negative to positive. Homes with one foot of freeboard sell at a 5.3% price premium, relative to homes without freeboard, in the wake of a flood. Interestingly, as Table 2 shows, this effect is driven by homes located in inland communities. One possible explanation for this pattern is that flooding provides more new information in inland areas where flood risk is less salient in the absence of a recent flood.

Figure 4 estimates the same effect – the price premium for freeboard in the wake of a recent flood – in an event study framework. We find that a flood in the 12 months preceding the property sale causes a 12% (95% CI = 1 to 23%) price premium for homes with freeboard. Floods that occur after the property is sold

have no detectable impact on the value of freeboard. This null effect of future floods lends confidence to the causal interpretation of our estimates. Floods more than 12 months before the sale also have no detectable effect, suggesting either that floods quickly lose salience for homebuyers.

The price premium for homes subject to freeboard requirements in the wake of a flood is consistent with the evidence in Section 4.2 that freeboard height is strongly associated with reduced property damages from flooding. Properties with freeboard may have suffered lower damage and are therefore able to command a higher price immediately after a flood event. However, for the average home in our sample, the magnitude of the estimated price premium is more than twice as large as the estimated reduction in flood damages based on our analysis of NFIP payouts. One possible explanation for this discrepancy is that a recent flood increases information about and salience of local flood risk, making flood-resistant homes more attractive to buyers.

We test for the presence of such an information channel by estimating the effect of freeboard on near-misses (homes in flooded communities that were not themselves inundated) in Column 3 of Table 3. We find no evidence that near-misses increase the value of homes with freeboard requirements, suggesting that the price premium for elevated homes in the wake of a recent flood is more likely driven by reduced property damages than increased flood risk saliency. Notably, freeboard is only required in FEMA Special Flood Hazard Areas, where flood risk should already be salient to buyers given that they are required to obtain flood insurance in order to be eligible for a federally-backed mortgage in these high risk areas.

Columns 2 and 4 of Table 3 show heterogeneity in willingness to pay for freeboard. One reason home buyers may not value elevated homes is accessibility concerns; stairs may present a challenge for older family members in accessing the home. To test for this possibility, the estimates in Column 2 allow for a differential price effect of freeboard in communities with a higher share of older individuals, where accessibility is likely a larger concern. The coefficient estimate for $Freeboard \times Seniorshare$ share suggests that for each 10 percentage point increase in the share of people over the age of 65, each foot of freeboard reduces property values by 1.1%. Thus moving from the median community (25% people over 65) to the 90th percentile (36% people over 65) increases the price discount associated with freeboard from 2.8% to 4.0%. This finding suggests that accessibility plays an important role in shaping taste for flood resistant homes. Thus it may not be irrational for home buyers not to demand elevated homes if this inconvenience cost outweighs expected savings in the event of a disaster.

Next, we test to what extent community-level compliance with freeboard standards affects willingness to pay for homes constructed after the adoption of freeboard requirements. Column 4 of Table 3 replicates our baseline analysis in the sub-sample of communities where we can estimate freeboard compliance levels based on data from the NFIP. We find that compliant communities experience significantly larger damages from

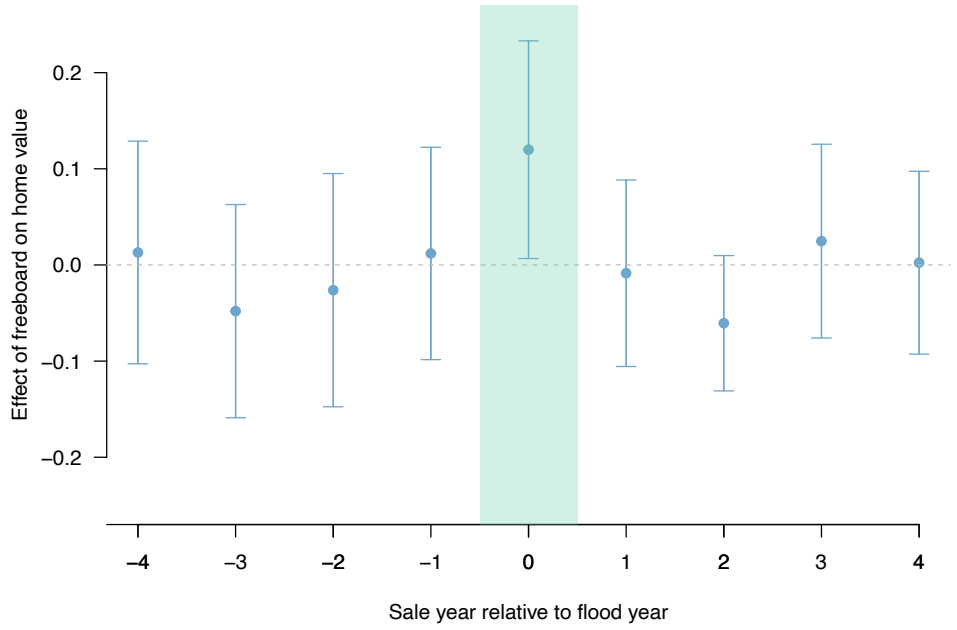
Table 3: Effect of freeboard requirements on property values

	Dependent variable: Log property sale price			
	(1)	(2)	(3)	(4)
Freeboard	-0.0310**	0.0006	-0.0175	-0.0575***
	(0.0131)	(0.0167)	(0.0313)	(0.0113)
Freeboard × Flooded	0.0840***	0.0865***	0.0852***	0.0162
	(0.0243)	(0.0243)	(0.0240)	(0.1015)
Flooded	-0.0278**	-0.0279**	-0.0279**	0.0675
	(0.0111)	(0.0111)	(0.0111)	(0.0540)
Freeboard × Senior share		-0.1139***		
		(0.0263)		
Freeboard × Community flood			-0.0207	
			(0.0338)	
Freeboard × Compliant share				0.0222
				(0.0190)
Flooded × Compliant share				-0.1270*
				(0.0638)
Freeboard × Flooded × Compliant share				0.0979
				(0.1181)
Linear combinations of coefficients				
Freeboard + Freeboard × Flooded	0.0530**	0.0871***	0.0677*	-0.0413
	(0.0235)	(0.0252)	(0.0365)	(0.1019)
Freeboard + Freeboard × Compliant				-0.0352***
				(0.0099)
Flooded + Flooded × Compliant				-0.0594**
				(0.0270)
Freeboard × Flooded +				0.1141**
Flooded × Freeboard × Compliant				(0.0411)
Observations	11,307,977	11,305,788	11,307,977	5,894,838

Notes: We estimate the effect of home values at the property-level using Equation (9). Column(1)-(3) includes all recorded property sales for homes built after the year 2000 and during the time period floods have been captured by the Global Flood Database (2001-2018). Column (4) is estimated in the subsample of communities that report freeboard height in NFIP claims and have at least 10 NFIP claims over the study period. A property is considered Flooded if inundated by a flood within 12 months before sale. Freeboard is the height difference between the base flood elevation and lowest flood elevation. Senior share is the percentage of households with seniors aged 65+. A property is in a flooded community if any property in that community was flooded within 12 months before sale. Compliant share is the fraction of homes meeting freeboard requirements (estimated using NFIP data). Property flood risk is proxied by number of flood hits, interacted with flood zone A and V. Regressions include controls for log versions of lot size, distance to CBD, shoreline distance, and riverine distance. Fixed effects include census tract, community-by-flood zone, community-by-year-month, and year built. Standard errors are clustered by state. Asterisks indicate statistical significance at the 10% (*), 5% (**), and 1% (***) levels.

flooding than non-compliant communities. The coefficient estimate on the interaction $Flooded \times Compliance\ share$ is -0.127, suggesting that moving from the median community with 74% compliance to the 90th percentile with 100% compliance increases the expected damages from a recent flood from 2.6% to 6.0% of

Figure 4: Effect of freeboard on housing values by years since flood



Notes: The differential effect of freeboard height (in feet) on home values in the event of a flood. The x-axis shows the sale year relative to the flood year. Year zero (highlighted in green) means the flood occurred in the one-year period prior to the sale. Positive values indicate the flood occurred before the sale. Negative values indicate the flood occurred after the sale. Dots show parameter estimates and bars show 95% confidence intervals.

the property value. The result that flood damages are larger compliant communities is consistent with the expectation that communities at higher risk of flooding are more likely to enforce flood codes.

The coefficient estimates on the interaction $Freeboard \times Compliance\ share$ represents the differential willingness to pay for freeboard in compliant communities. The coefficient is positive but statistically indistinguishable from zero. A positive coefficient here could reflect higher willingness to pay for freeboard in higher risk communities. Finally, the linear combination of coefficients reported in the last row of Table **??**, which represents the price premium associated with elevated homes in communities with 100% compliance after a flood is 11.4%. At the same time, the there is no detectable effect of freeboard after flooding in non-compliant communities. These two findings are in line with the expectation that freeboard requirements should only reduce property damages from flooding if they are actually implemented on the ground.

Overall, our results imply that home buyers do not demand flood-resistant homes. In fact, the negative willingness to pay for homes with freeboard requirements suggests that home buyers prefer homes without flood codes. Willingness to pay for homes with freeboard requirements increases after a recent flood. However, a sale after flooding is rare; less than 3% of floodplain homes in our sample were flooded in the year preceding the sale. These results shed new light on why we do not see widespread proliferation of freeboard. Despite the fact that freeboard requirements do significantly reduce flood damages, builders have financial

incentives not to elevate homes given buyers strong distaste for freeboard.

5 Discussion

Annual economic losses from natural disasters in the United States now exceed $100 billion and have risen, on average, more than six percent per year since 1980. Losses are expected to rise in the future with global climate change and growing exposure of people and property in disaster-prone areas. These escalating costs have made it a social and policy priority to increase resiliency to natural disasters. One important component of this effort will be designing buildings and other infrastructure to better withstand floods, hurricane winds, fires, and seismic hazards. However, despite the development of hazard-resistant building codes and decades of advocacy by FEMA for states and communities to adopt these codes, proliferation of hazard-resistant building practices remains low.

This study seeks to understand why communities and individuals fail to adopt flood-resistant building practices, despite information campaigns that claim these codes generate large savings for homeowners. Using parcel-level data on housing market outcomes, we show that home buyers have a strong distaste for flood-resistant homes, despite the fact that these homes suffer significantly lower damages in the event of a flood. Notably, a recent flood increases willingness to pay for flood-resistant homes.

Our results have several implications for policy-making. First, we find that realized savings from elevating homes fall short of simulated savings. This result could reflect shortcomings in the idealized models, which do not appear to reflect empirically-estimated depth damage functions, both based on the findings of this study and Wing, Pinter, et al. 2020. We echo the recommendation in Wing, Pinter, et al. 2020 to revisit depth-damage functions using large empirical datasets such as the NFIP claims database, and further add that these data can allow for identifying heterogeneity in damage functions by resilience measures, as we do here with freeboard. Another reason realized savings may fall short of simulated savings is imperfect compliance with hazard-resistant codes. About 15% of new homes in communities with freeboard requirements do not meet official standards, and compliance is lower in many communities. Monitoring and enforcement of hazard-resistant codes may be required because builders have financial disincentive to implement these codes since willingness to pay is negative.

Second, hazard-resistant building practices may be associated with inconveniences that slow their uptake. In the case of elevated homes, we show that accessibility concerns reduce demand for this flood-resistant building practice. Such inconveniences should be considered when designing hazard-resistant codes so that they do not interfere with adoption. For example, perhaps flood codes could encourage also elevating driveways to the lowest floor elevation or building access ramps instead of stairs to exterior doors.

Third, it is notable that floods increase willingness to pay for flood-resistant homes, but not for nearby properties that were not inundated by the flood and thus are unlikely to have suffered any damage. We interpret this pattern as prices increasing for elevated homes in the wake of a flood because they suffer lower property damages, not because the flood increases information about and/or salience of flood risk.

Our study has important limitations. First, our analysis focuses on one major flood code, freeboard, instead of the many flood provisions recommended as part of International Residential Codes (IRCs). We focus on freeboard for a number of reasons; it is the only code we can observe in our data at the community-level and over time, it is the only flood code that is modeled in FEMA's study that estimates the savings associated with hazard-resistant codes, and it is widely thought to be both the most effective and the costliest flood provision. Still, other flood provisions may have different effects on housing market outcomes. A second limitation is that because we cannot observe parcel-level freeboard heights in our housing market impacts analysis, in practice we are estimating willingness to pay for freeboard requirements rather than freeboard itself. Given incomplete compliance (data from NFIP claims indicates that about 85% of new homes in areas with freeboard requirements are compliant), our estimates may be biased downwards. Third, there is most likely heterogeneity in freeboard valuations that is not fully captured by our analysis. In ongoing work for this paper, we are investigating heterogeneity in the savings associated with freeboard by property characteristics and flood risk, as well as heterogeneity in freeboard valuations across different regions and segments of the population.

Nonetheless, our results shed light on the natural disaster "adaptation puzzle," where individuals seem to under-adopt cost-effective resilience measures. In our setting, we find that flood-resistant building codes are unlikely to proliferate on their own and policymakers ought to take care to weigh the full costs of building codes against their benefits. Indeed, the lack of adoption may be rational since flood-resistant homes appear to have previously unquantified inconvenience costs. Still, we show that there is room for information interventions to increase uptake of hazard-resistant codes.

References

Bakkensen, Laura A and Lint Barrage (2022). "Going underwater? Flood risk belief heterogeneity and coastal home price dynamics". In: *The Review of Financial Studies* 35.8, pp. 3666–3709.

Bhola, Vijai et al. (2023). "Escalating Costs of Billion-Dollar Disasters in the US: Climate Change Necessitates Disaster Risk Reduction." In: *The Journal of Climate Change and Health*, p. 100201.

Corelogic (2022). *Climate Change Catastrophe Report*.

Czajkowski, Jeffrey, Kevin M Simmons, and James M Done (2017). "Demonstrating the intensive benefit to the local implementation of a statewide building code". In: *Risk Management and Insurance Review* 20.3, pp. 363–390.

Deryugina, Tatyana (2013). "Reducing the cost of ex post bailouts with ex ante regulation: Evidence from building codes". In: *Available at SSRN 2314665*.

Dolšak, Nives and Aseem Prakash (2018). "The politics of climate change adaptation". In: *Annual Review of Environment and Resources* 43, pp. 317–341.

Dumm, Randy E, G Stacy Sirmans, and Greg Smersh (2011). "The capitalization of building codes in house prices". In: *The Journal of Real Estate Finance and Economics* 42, pp. 30–50.

FEMA (2018). *2018 International Building Codes [a complication of flood-resistant provisions, prepared by FEMA]*.

— (2020a). *Building Codes Save: A Nationwide Study*.

— (2020b). *Protecting Communities and Saving Money: The Case for Adopting Building Codes*.

— (n.d.). *Building Higher in Flood Zones: Freeboard – Reduce Your Risk, Reduce Your Premium*. URL: https://www.carteretcountync.gov/DocumentCenter/View/2238/Benefits-of-Freeboard#:~:text=Benefit%2DCost%20Comparison,for%20each%20foot%20of%20freeboard..

Fowlie, Meredith, Michael Greenstone, and Catherine Wolfram (2018). "Do energy efficiency investments deliver? Evidence from the weatherization assistance program". In: *The Quarterly Journal of Economics* 133.3, pp. 1597–1644.

Gallagher, Justin (2014). "Learning about an infrequent event: Evidence from flood insurance take-up in the United States". In: *American Economic Journal: Applied Economics*, pp. 206–233.

Hino, Miyuki and Marshall Burke (2021). "The effect of information about climate risk on property values". In: *Proceedings of the National Academy of Sciences* 118.17, e2003374118.

Kousky, Carolyn and Erwann Michel-Kerjan (2017). "Examining flood insurance claims in the United States: Six key findings". In: *Journal of Risk and Insurance* 84.3, pp. 819–850.

Levinson, Arik (2016). "How much energy do building energy codes save? Evidence from California houses". In: *American Economic Review* 106.10, pp. 2867–2894.

Ostriker, Abigail and Anna Russo (2024). "The effects of floodplain regulation on housing markets". In: *URL https://ostriker.github.io/papers/Ostriker-Russo_floodplain_regulations.pdf*.

Porter, Kevin et al. (2019). *Natural Hazard Mitigation Saves: 2019 Report*. National Institute of Building Sciences.

Tellman, Beth et al. (2021). "Satellite imaging reveals increased proportion of population exposed to floods". In: *Nature* 596.7870, pp. 80–86.

Vaughan, Ellen and Jim Turner (2013). "The value and impact of building codes". In: *Environmental and Energy Study Institute White Paper* 20, pp. 501–517.

Wagner, Katherine RH (2022). "Adaptation and adverse selection in markets for natural disaster insurance". In: *American Economic Journal: Economic Policy* 14.3, pp. 380–421.

Wing, Oliver EJ, William Lehman, et al. (2022). "Inequitable patterns of US flood risk in the Anthropocene". In: *Nature Climate Change* 12.2, pp. 156–162.

Wing, Oliver EJ, Nicholas Pinter, et al. (2020). "New insights into US flood vulnerability revealed from flood insurance big data". In: *Nature communications* 11.1, p. 1444.

Supplemental Information

(Un)willingness to pay for flood-resistant homes

Hannah Druckenmiller
Jaimie Choi
Billy Babis
Michael Toman

A Extended Data and Methods

A.1 Data Construction

Flood damages. The data we use to estimate the effect of freeboard height on damages from flooding, as measured by NFIP payouts, is at the flood insurance claim-level. We begin with the FIMA NFIP Redacted Claims Dataset (v2).[6]. We first construct a measure of relative damage for each claim, defined as total property damages (building damage amount + contents damage amount) divided by total property value (building property value + contents property value). We measure freeboard height for each property using the reported elevation difference between base flood elevation and lowest floor elevation. We limit our sample to claims with elevation differences between -1 and 30 feet and construct four bins of freeboard height: <= 0 feet, 1 foot, 2 feet, 3 feet, and >= 4 feet. We windsorize the sample to include properties with values between the 1st and 99th percentiles. We further limit our sample to observations with relative damages less than or equal to one and only one floor in the insured building, following Wing, Pinter, et al. 2020.

Housing market impacts. The data we use to estimate the effect of freeboard height on housing market impacts is at the transaction-level. We begin with all residential property sales from the Corelogic owner transfers database, excluding sales in Alaska and Hawaii. We limit our sample to detached-single-family homes built in the year 2000 or later, as this is the first year for which we have data on freeboard adoption. We focus on homes built before or on the sale year to ensure freeboard saliency even to buyers of newly constructed homes. To remove outliers, properties with incorrect information (e.g., mis-coded vacant lots), and problematic properties (e.g., sold with liens, severely deteriorated), we use the following filters:

1. Restrict housing prices to be between $50,000 - 5$ million dollars. Remove top and bottom 1% priced-homes for each state-year.
2. Restrict lot size to be strictly greater than 0 and less than 10 acres.

Table A1: CoreLogic Property Sales Summary Statistics

Variable	Mean	SD	Min	Max	Median
Year Built	2006.63	4.99	2000.00	2018.00	2005.00
Sale Year	2010.68	5.26	2001.00	2018.00	2011.00
Sale Price	308,238.24	205,475.67	50,000.00	4,400,000.00	255,000.00
Lot Acres Size	0.40	0.77	0.00	10.00	0.20

We intersect the coordinates of each property with the National Flood Hazard Layer to identify it's NFIP community and FEMA-designated flood zone. We then merge the property-level data with our community-by-flood zone data on annual freeboard requirements such that each property is linked with the freeboard

[6]Available at: https://www.fema.gov/openfema-data-page/fima-nfip-redacted-claims-v2

requirements that were in place at the time of construction. Next, we intersect the property sales data with flood inundation maps from the Global Flood Database for US flood events. These data include 110 large regional floods between 2001 and 2018. This intersection allows us to observe whether the property was flooded in the years immediately preceding or following the sale.

Finally, we construct property-level controls for distance to the central business district (CBD) using NHGIS place points to define CBDs, distance to the shoreline using NOAA's national shoreline shapefile, and distance to riverine features using ESRI's US major river shapefile. For both the distance to the shoreline and riverine features, due to computational limitations, we calculated the distance of properties within 100 miles of the river and shoreline. Distances beyond 100 miles are top-coded as the maximum property distance. To account for bias due to top-coding, for shorelines, we implement a discrete-continuous control by interacting shoreline distance with whether the property is in a state with a shoreline. Since all states contain a major river, we retain the riverine distance measure as is.

A.2 Estimating equations for extensions

Flood damages. Section 3.2 describes our baseline estimating equation for the effect of freeboard height on damages from flooding. As described in the main text, we estimate two alternative specifications.

First, we allow for a non-linear relationship between freeboard height and flood damages. The estimating equation is:

$$damage_{ijczy} = \sum_{h=1}^{4} [\alpha_h freeboard_{hi}] + \beta BFE_i + \gamma_j + \lambda_c + \omega_z + \delta_y + \epsilon_{ijczy} \tag{5}$$

where the treatment variables $freeboard_{hi}$ are indicators (0/1) for whether the property has a freeboard height in one of four bins: 1 foot, 2 feet, 3 feet, or 4+ feet. The reference category, which is omitted from the regression, is properties with freeboard heights of less than one foot. All other variables are defined as in equation 3.

Second, we estimate flood depth-damage functions, allowing for differential responses for properties with and without freeboard. The estimating equation is

$$damage_{ijczy} = \sum_{d=1}^{10} [\alpha_d depth_{di} + \beta_d (depth_{di} \times freeboard_i)] + \gamma freeboard_i + \epsilon_{ijczy} \tag{6}$$

where $depth_d$ are a set of indicator variables for reported flood depths, in increments of 1 foot, from 1 to 10 feet. Here, $freeboard$ is indicator for freeboard equal to one for properties with at least one foot of freeboard height and zero otherwise. The parameters α_d estimate property damages by flood depth for homes without freeboard. The parameters β_d estimate the differential damages by flood depth for homes with freeboard.

Housing market impacts. Section 3.2 describes our baseline estimating equation for the effect of freeboard height on damages from flooding. As described in the main text, we estimate four alternative specifications.

First, we estimate the differential price effect after a flood in an event study framework. The estimating equation is:

$$\begin{aligned} ln(price_{ictjszy}) = \alpha Freeboard_{jzc} + \sum_{\tau=-4}^{4} [\beta_\tau (Flooded_{iy}^{\tau} \times Freeboard_{jzc}) + \gamma_\tau Flooded_{iy}^{\tau}] \\ + \zeta \mathbf{X_i} + \lambda_c + \theta_t + \mu_{jz} + \delta_{jy} + \epsilon_{ictjzy} \end{aligned} \tag{7}$$

where all variables are defined as in Equation 9, except here we include annual leads and lags of flood events (relative to the sale year). The parameters of interest are the β_τ, which describe the differential price effect of freeboard for properties where a flood occurred in the years preceding and following the sale.

Second, we allow for a differential willingness to pay for freeboard in communities with a higher share of households with 65+ seniors, where accessibility may present a larger concern. We estimate the equation

$$
\begin{aligned}
ln(price_{ictjszy}) = {} & \alpha Freeboard_{jzc} + \beta(Flooded_{iy} \times Freeboard_{jzc}) + \gamma Flooded_{iy} \\
& + \nu SeniorShare_{j} + \omega(SeniorShare_{j} \times Freeboard_{jzc}) \\
& + \zeta \mathbf{X_i} + \lambda_c + \theta_t + \mu_{jz} + \delta_{jy} + \epsilon_{ictjzy}
\end{aligned} \tag{8}
$$

where all variables are defined as in Equation 9, except here we include an interaction between $Freeboard$ and the share of households with 65+ year old individuals.

Third, we estimate the effect of "near-misses" on willingness to pay for freeboard. We define a near-miss as a flood that hit the community in which the property is located, but did not inundate the property itself. We estimate the equation

$$
\begin{aligned}
ln(price_{ictjszy}) = {} & \alpha Freeboard_{jzc} + \beta(Flooded_{iy} \times Freeboard_{jzc}) + \gamma Flooded_{iy} \\
& + \beta_2(CommunityFlood_{jy} \times Freeboard_{jzc}) + \gamma CommunityFlood_{jy} \\
& + \zeta \mathbf{X_i} + \lambda_c + \theta_t + \mu_{jz} + \delta_{jy} + \epsilon_{ictjzy}
\end{aligned} \tag{9}
$$

where all variables are defined as in Equation 9, except here we include an indicator variable for the community being hit by a flood in the year preceding the sale ($CommunityFlood$) and an interaction between this term and $Freeboard$. Here, the differential price effect for freeboard after a near-miss is captured by β_2 and the differential price effect for freeboard after a flood that inundated the property is estimated by $\beta_1 + \beta_2$.

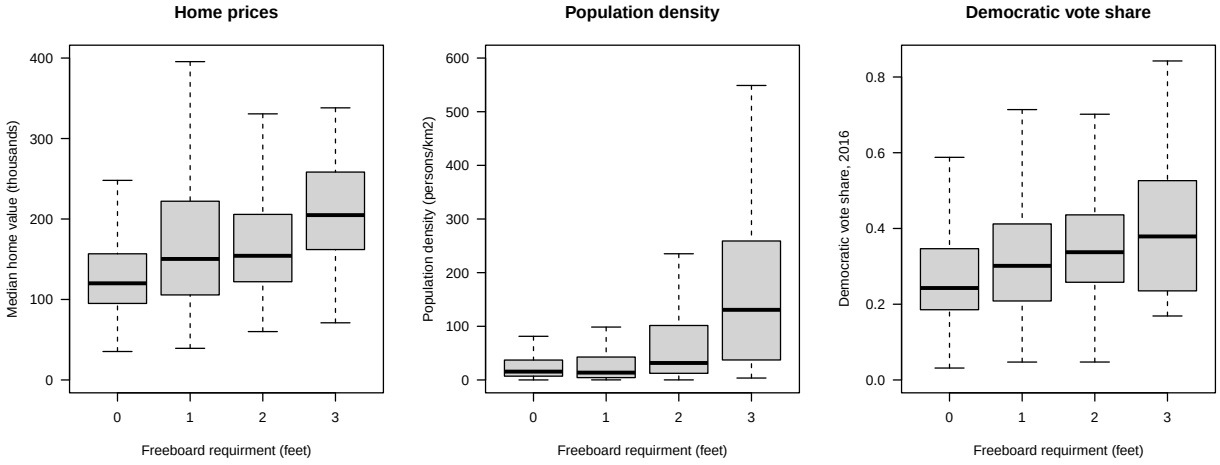
Finally, we allow for heterogeneity in the price effects of freeboard by community compliance with freeboard requirements. We define compliant share ($Compliant$) as the percentage of properties in NFIP policy data, which reports the year of construction and freeboard height– coded as 'elevation difference'–, that have freeboard heights at or above local freeboard requirements at the time of construction. We use the equation

$$
\begin{aligned}
ln(price_{ictjszy}) = {} & \alpha_1 Freeboard_{jzc} + \beta_1(Flooded_{iy} \times Freeboard_{jzc}) + \gamma_1 Flooded_{iy} \\
& + \alpha_2(Freeboard_{jzc} \times Compliant_{j}) + \beta_2(Flooded_{iy} \times Freeboard_{jzc} \times Compliant_{j}) \\
& + \gamma_2(Flooded_{iy} \times Compliant_{j}) + \zeta \mathbf{X_i} + \lambda_c + \theta_t + \mu_{jz} + \delta_{jy} + \epsilon_{ictjzy}
\end{aligned} \tag{10}
$$

where all variables are defined as in Equation 9, except here we include interaction terms between $Compliant$ and the $Freeboard$ and $Flood$ variables. Here, α_1 and β_1 give the price effect of freeboard and the differential effect of freeboard after a recent flood, respectively, for homes in non-compliant communities. The same effects for homes in compliant communities are estimated by $\alpha_1 + \alpha_2$ and $\beta_1 + \beta_2$.

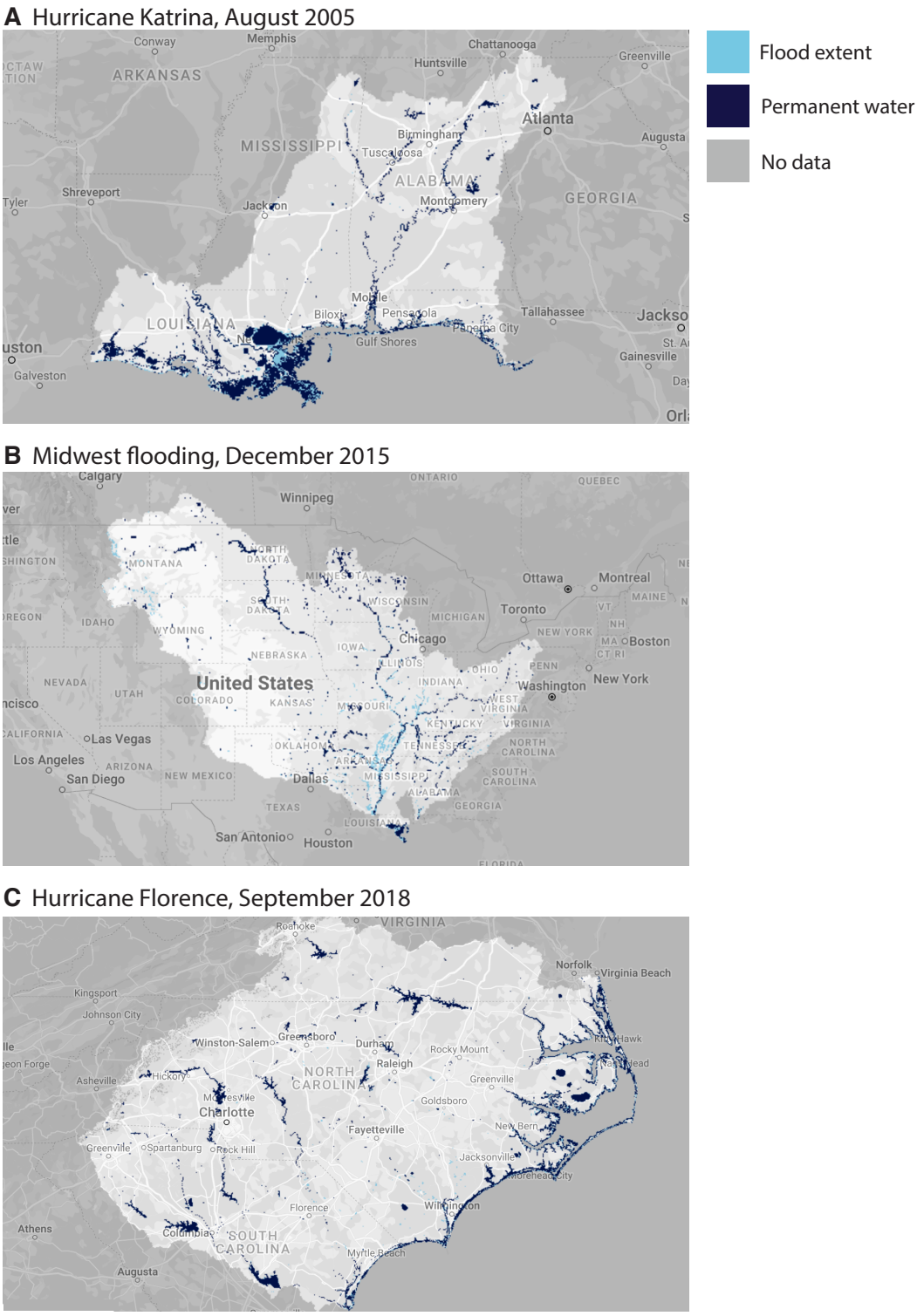
B Supplemental Tables and Figures

Figure A1: Freeboard adoption correlates



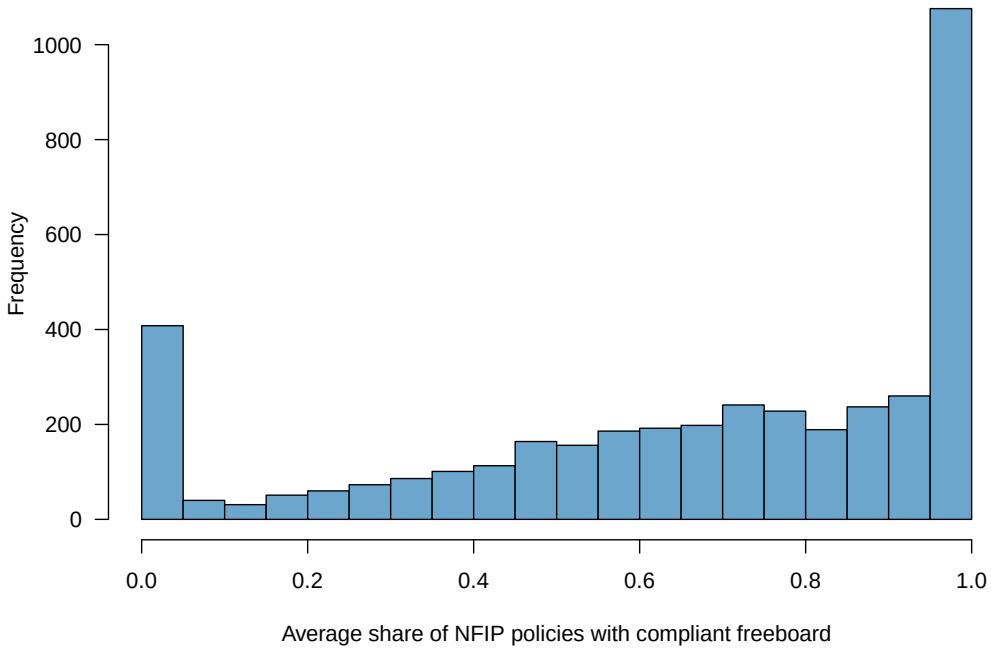
Notes: We show the distribution of median home values (left), population density (middle), and democratic vote share (right).

FIGURE A2: EXAMPLE FLOOD INUNDATION MAPS



Notes: Three example flood inundation maps from the Global Flood Database (GFD). Data are at 250 meter resolution. Flood extent is shown in light blue and permanent waters are shown in dark blue. The full database is available at: https://global-flood-database.cloudtostreet.ai/

FIGURE A3: COMPLIANCE WITH FREEBOARD REQUIREMENTS



Notes: We calculate the share of NFIP policies for which the home is complaint with freeboard requirements at the time of construction across NFIP communities. We limit the sample to NFIP communities with at least 10 NFIP policies.