The effect of information about climate risk on property values

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Floods and other climate hazards pose a widespread and growing threat to housing and infrastructure around the world. By reflecting climate risk in prices, markets can discourage excessive development in hazardous areas. However, the extent to which markets price these risks remains poorly understood. Here we measure the effect of information about flood risk contained in regulatory floodplain maps on residential property values in the United States. Using multiple empirical approaches and two decades of sales data covering the universe of homes in the United States, we find little evidence that housing markets fully price information about flood risk in aggregate. However, the price penalty is larger for commercial buyers and in markets where buyers are more risk aware, suggesting that policies to improve risk communication could influence market outcomes. Our findings indicate that houses in flood zones in the United States are currently overvalued by a total of $43.8 billion (95% confidence interval: $32.6 to $55.6 billion) based on the information in publicly available flood hazard maps alone, raising concerns about the stability of real estate markets as climate risks become more salient and severe.

climate change | flood risk | real estate

Global economic losses from natural hazards have increased nearly 10-fold since the 1970s, with the United States experiencing $300 billion in losses in 2017 alone (1–3). This trend is primarily driven by an increase in the number of people and amount of wealth concentrated in locations exposed to tropical cyclones, floods, and other hazards (4). Managing development in such areas is therefore critical to limiting losses from natural hazards, particularly as climate change alters the frequency and intensity of extreme weather events.

One view is that markets should be able to manage this risk efficiently. With complete information, efficient real estate markets capitalize flood risk: The potential flood damage reduces the value of flood-prone property relative to otherwise identical low-risk property, which in turn reduces the incentive to develop in flood-prone locations. In the United States, to support market efficiency, the federal government produces publicly available maps that delineate areas with a $\geq$1% chance of flooding in any given year, referred to as the Special Flood Hazard Area or the "floodplain." These maps, officially known as Flood Insurance Rate Maps (FIRMs), are the primary source of information on flood risk for individuals and communities, and they are often used as the basis for other local land use regulations. Accordingly, the federal government regularly budgets over $100 million annually for floodplain mapping activities, with fiscal year 2018 funding of $262.5 million (5, 6). Properties purchased with a federally backed mortgage in the floodplain are required to carry flood insurance, which is overwhelmingly provided by the National Flood Insurance Program (NFIP). NFIP pricing depends heavily on whether the property is inside or outside of the floodplain (7).

Past research offers mixed evidence on whether markets efficiently capitalize the flood risk information in these maps. While the majority of studies suggest a price penalty for being in the floodplain, point estimates range from a −75.5% penalty to a 61.0% bonus (8). These discrepancies may arise because the vast majority of these studies are cross-sectional and thus vulnerable to bias if researchers cannot control for the many factors that are correlated with both flood risk and prices. In addition, individual estimates are often based on data from a single county or city, which may contribute to the wide range observed (Fig. 1). Of the few non–cross-sectional studies, results are mixed: In Center County, PA, rezoning into a floodplain reduced property values, but rezoning out of a floodplain had no effect (9). In New York City, NY, the release of preliminary new flood maps reduced property values, but the effect differed sharply between properties that had and had not flooded during Superstorm Sandy (10).

Here we conduct a nationwide evaluation of the effect of these regulatory floodplain maps on property values, which we refer to as the "flood zone discount." We construct a timeseries of floodplain maps by gathering compact discs containing historical floodplain data from multiple libraries, converting the data into shapefiles, and overlaying them with current floodplain maps. We isolate the effect of the floodplain maps on property values by taking advantage of both spatial and temporal variation in flood zone assignment. The floodplain maps are highly spatially granular, such that the floodplain often splits houses on the same block or divides one side of the street from another (*SI Appendix*, Fig. S1). In addition, the maps are updated at different times around the country (*SI Appendix*, Fig. S2) based on factors

Significance

Understanding whether markets efficiently price environmental risk is critical to policy design, particularly as key climate risks change rapidly. We conduct a nationwide analysis of the extent to which the US housing market prices information about flood risk contained in publicly available flood maps. Using data on millions of home sales, we find that information in these maps is not fully capitalized in property values. Lack of information appears to contribute to underpricing: More sophisticated commercial buyers and more risk-aware buyers respond more to floodplain information. This underpricing increases incentives to develop in hazardous places. Enhanced communication of flood risk could help ensure such risk is appropriately reflected in market outcomes.

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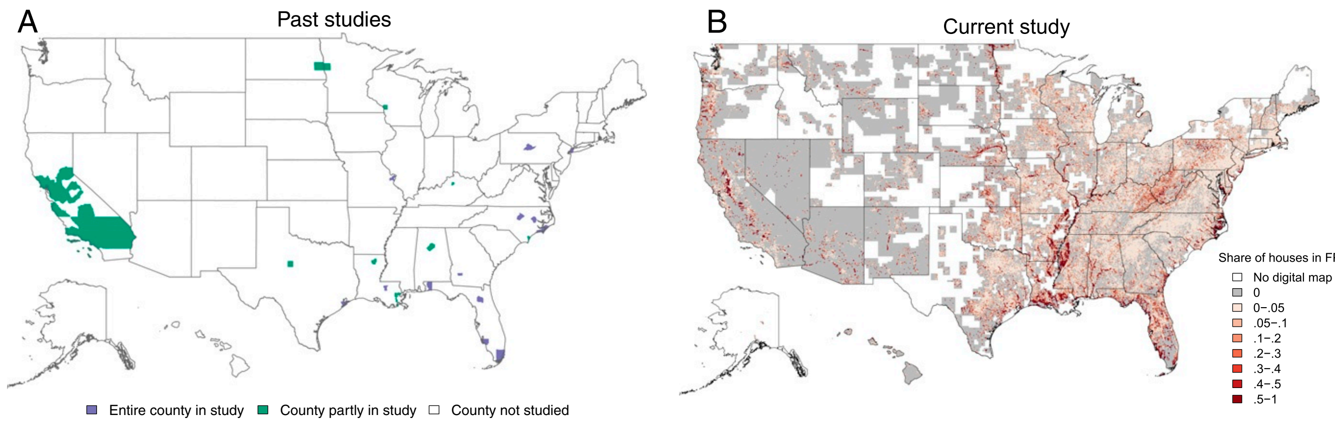

Fig. 1. Geographic coverage of empirical estimates of the flood risk discount in the United States. (*A*) Locations of past studies estimating the flood risk discount. Existing studies have typically evaluated a single county or city at a time. Sources included are listed in *SI Appendix*, Table S1 and do not include a broader set of studies focused on other aspects of flood risk in the United States. (*B*) Geographic coverage of data used in this study mapped on a 5 × 5-km grid. The areas in white did not have a digitized floodplain map at the time of download. Areas in gray are included in the National Flood Hazard Layer but contain either no single-family homes or no floodplain single-family homes. Darker shades of red indicate a higher proportion of single-family homes in the floodplain within the grid cell. Approximately 3.8 million single-family homes are currently located in floodplains included in this analysis.

including the age of the current floodplain map, the population and assets located in the area, recent rates of development, and availability of new data (11).

We combine these changes in floodplain maps with detailed proprietary data on the universe of real estate transactions in the United States to implement three methods for estimating the flood zone discount: panel, difference-in-difference, and cross-section (*Materials and Methods*). In the panel approach, our preferred method, we estimate the flood zone discount by comparing individual houses to themselves over time as they are rezoned from outside to within the floodplain due to map updates, controlling flexibly for changes in local market conditions. The difference-in-difference mimics this approach, but instead of comparing a single house to itself, compares small geographic areas over time. Finally, for the sake of comparison to earlier work, we compare floodplain houses to nonfloodplain houses in a cross-sectional analysis, controlling for a suite of location- and property-specific characteristics. This latter method, while common in the historical literature on flood risk, is no longer considered a reliable approach for causal inference in the applied econometrics literature, given the near impossibility of controlling for all characteristics that might be different across properties but correlated with flood risk and prices.

Importantly, the flood zone discount captures the impact of the information embedded in floodplain maps and differs from the flood risk discount for multiple reasons. For example, flood risk is continuous, not categorical as depicted in the maps. In addition, the map updates often capture changes in flood risk that predate the map itself, such as large-scale development that increased impervious surface cover. The map update changes key information available to the market about the level of risk, rather than changing the "true" risk. For most buyers, the flood zone designation also introduces the mandatory insurance requirement and thus affects their total financial costs. Insurance prices through the NFIP change substantially at the floodplain boundary even if underlying risk does not. Most nonfloodplain homes qualify for Preferred Risk Policies that cost \$300 to \$500/y, while the same amount of coverage for a floodplain home can easily cost double that amount. The relatively higher cost of insurance in the floodplain may also be an important information signal about the underlying risk to the property. Therefore, the effect of updated floodplain maps on housing prices will reflect multiple changes that occur when crossing the flood zone boundary. Because we focus on the flood zone discount, we do not aim to evaluate how accurately the floodplain maps capture true flood risk; rather, we take the floodplain maps as provided and estimate the effect of the information they contain. Our estimates therefore do not capture hazards that are not mapped or future increases in hazard, which we discuss further later on.

In the second part of our analysis, we examine spatial heterogeneity in our estimated effects to evaluate drivers of the flood zone discount, relying solely on our preferred panel specification. We focus on the role of information about flood risk, as it has previously been identified as an obstacle for real estate market participants. For example, in a survey of Colorado floodplain homeowners, only 8% found out about flood risk to the property before they made an offer, and 69% said they would have changed their offer had they known about flood risk and insurance prices beforehand (12). In addition, the passage of a stringent law in California that required disclosure of flood risk during real estate transactions was found to increase the price penalty for flood risk (13). We study multiple plausible sources of variation in information about flood risk: whether the buyer is a commercial buyer, a group likely to have more experience purchasing real estate and greater resources to seek out flood-related information than individuals and households, and the stringency with which states require sellers to disclose information about flood risk and flood history to buyers. In both cases, we hypothesize that increased information on the part of the buyer will lead to a larger flood zone discount.

Results

Across the universe of single-family home sales in the United States, we find in our preferred panel specification (n = 5.65 million sales) that being zoned into the floodplain reduces property values by −2.1% (95% CI: −4.2 to 0.1%) (Fig. 2 and *SI Appendix*, Table S3). The difference-in-difference estimate (n = 5.64 million) is similar at −1.4% (−3.0 to 0.2%), while the cross-sectional estimate (n = 17.6 million), which is again unlikely to represent an unbiased estimate of the flood zone discount, is positive at 1.7% (0.6 to 2.8%).

To provide context for these estimates, we compare our results to two different benchmarks. Our first benchmark approximates the expected flood zone discount in an efficient market. The difference between a floodplain home and an otherwise identical

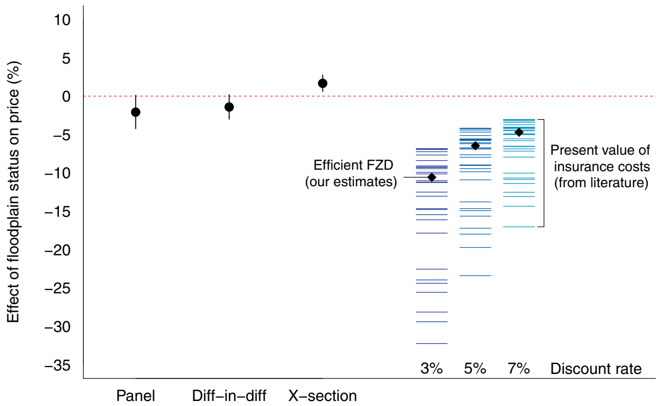

Fig. 2. Information about flood risk is not fully reflected in property values. The results of each method are shown at left, with error bars marking 95% confidence intervals (n from left to right: 5.65, 5.64, and 17.6 million). At right, the diamonds denote our estimates of the efficient flood zone discount, approximated as the present value of insurance costs when the household is fully insured as a percentage of the property's total value. The rug plots show literature estimates of the present value of reported insurance costs as a percentage of total property value. The diamonds and rug plots are shown under different discount rates. Summary statistics for the underlying data are shown in *SI Appendix*, Table S2.

safe home can be measured in three ways: 1) the present costs of expected flood damages, 2) the present costs of fully insuring the property against flooding, or 3) a combination of insurance costs and expected damages of the uninsured portion. The efficient market would price the minimum of those three quantities; if it is cheaper to insure than to bear the expected losses, then insurance costs would be priced, and vice versa. In practice, however, homeowners do not have access to property-level expected flood damage estimates, and the majority of home buyers are required to purchase at least partial flood insurance. Therefore, the cost of full insurance serves as a reasonable proxy for the "efficient" flood zone discount. We use data on insurance prices from the NFIP, assuming that houses are fully insured with the minimum deductible, such that virtually all of the costs from flooding would be covered by the insurance policy (*Materials and Methods*). Using this approach, we estimate that full pricing of presence in the floodplain would affect property values by −4.7% to −10.6%, depending on time discount rate (Fig. 2, black diamonds). We use these numbers as our best estimate of the flood zone discount in an efficient market—one that fully reflects publicly available information—but recognize that the precise value of the efficient flood zone discount will vary by property. *SI Appendix*, Fig. S3 illustrates the uncertainty in our estimates and the effect of changes in insurance costs on the efficient flood zone discount, and *SI Appendix*, Fig. S4 shows sensitivity to two particularly influential parameters, structure value and elevation.

As our second benchmark, we examine the actual financial burden from flood insurance experienced by homeowners. This quantity differs from the efficient flood zone discount because many homeowners are likely to be under- or uninsured and bear nonzero expected flood losses. We calculate the present value of a future stream of insurance costs as a percentage of total property value based on past papers that report both an average insurance cost and an average property price for the study area. These estimates are frequently used as the relevant benchmark in the literature. At a 5% discount rate, these estimates average −9%, ranging from −4% to −20% (Fig. 2, blue lines).

Our empirical estimates of the flood zone discount from both the panel and difference-in-difference designs are smaller than these benchmark results, indicating that floodplain presence is not fully reflected in property values. Including other sets of control variables yields estimates that are similar or even closer to 0 than these main estimates, lending further support to this finding (*SI Appendix*, Figs. S5 and S6).

To test the robustness of our results, we examine several aspects of the map updating process. First, there is potential for manipulation by local officials, such that only certain types of homes and neighborhoods are zoned into the floodplain. While the maps are subject to political pressure, the deliberation requires engineering and flood modeling studies to adjust the Federal Emergency Management Agency's (FEMA's) initial maps (14, 15). As such, while local politicians can invest in new studies or data collection efforts, adjustments must have some evidence base. We do not find a larger flood zone discount when we include census tract-by-year time controls, which would account for finer-scale time trends and the possibility that only certain neighborhoods are affected by map updates (*SI Appendix*, Figs. S5 and S6).

Second, it is possible that specific events or trends trigger map updates, such as major floods or rapid population growth. The map updating process itself is quite lengthy, and based on the sales in our panel sample, the lag between prior disaster declaration and map update is highly variable (*SI Appendix*, Fig. S7). Given that, and that we include only sales since a property's most recent substantial renovation, we do not expect sales of flood-damaged properties to be heavily overlapping with sales of rezoned properties. Further, for any time trends to be problematic, they must uniquely affect properties that are going to be rezoned into the floodplain in the future, rather than affecting the community overall. Therefore, a broad increase in real estate prices across a county would not affect our estimates.

Third, because the flood map updating process often takes multiple years, it is possible that the market has already adjusted to that information by the time the maps become official (which is the date recorded in our data). We evaluate this possibility using the difference-in-difference specification to test whether the flood zone discount emerges earlier in time than the official flood map update. We move the true dates of map update forward in time by 2 y and limit our sample to sales before the map is truly updated. With the false treatment date, our estimated flood zone discount shifts to +0.8% (−0.3 to 2.0%), compared to −1.4% (−3.0 to 0.2%) with the true treatment dates (*SI Appendix*, Fig. S8 and Table S6). These results mitigate concerns about anticipatory effects. Given evidence that a small fraction of homeowners learn about being in a floodplain before they make an offer on the house, the lack of an anticipatory reaction—which would require extremely well-informed buyers—is not surprising (12).

Finally, we test for price effects in the 500-y floodplain. Municipalities and lenders may occasionally use the 500-y floodplain to implement specific building codes or insurance requirements. We run this test by removing all properties in the 500-y floodplain under the historical maps and adding a treatment variable for being sold in the new 500-y floodplain, analogous to our main treatment of being sold in the new 100-y floodplain. We estimate a discount for the 100-y floodplain of −1.8% (−4.4 to 0.9%), comparable to our main result of −2.1%, and our estimated discount for the new 500-y floodplain is 1.0% (−0.4 to 2.4%) (*SI Appendix*, Table S7).

Access to Information. While aggregate nationwide results show little evidence that information about flood risk is fully priced in property markets, we find evidence of a larger flood zone discount in markets with better-informed buyers.

First, in states with strict real estate disclosure laws concerning flood risk, we find strong evidence of a flood zone discount (Fig. 3 and *SI Appendix*, Table S8). States have adopted widely

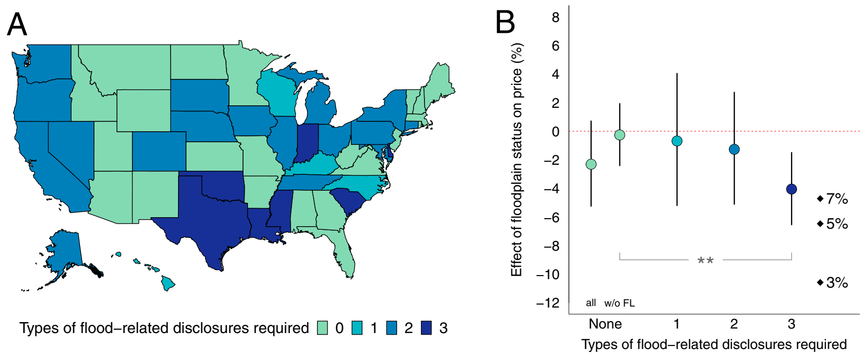

Fig. 3. The flood zone discount appears larger in states with very strict real estate disclosure laws concerning flood risk. (*A*) The types of flood-related real estate disclosures required in each state. Three types of disclosures are considered: floodplain location, flood damage, and flood insurance. (*B*) Estimates of the flood zone discount based on the types of flood-related real estate disclosures required (n = 5.65 million). States are grouped based on coloring in *A*. Error bars denote 95% confidence intervals. Asterisks denote the statistical significance of differences between groups: **$P < 0.05$. The diamonds, at right, mark estimates of the efficient flood zone discount under different time discount rates.

varying policies on what information a seller must disclose to a potential buyer and when. Some states require no disclosures at all, while Louisiana, a state with an extremely comprehensive policy, requires a disclosure form that includes whether flooding has ever been experienced, the flood zone classification (and the source and date of the information), whether there is flood insurance on the property, whether the seller has a flood elevation certificate, whether the seller or previous owner received any form of federal flood assistance, and whether there are any requirements to maintain flood insurance on the property. We classify the states based on three types of flood-related disclosures: 1) location in the floodplain, 2) flood damage, and 3) flood insurance (*Materials and Methods*). In the strictest states—those requiring all three types of disclosures—the estimated flood zone discount is −4.1% (−6.5%, −1.5%), compared to our nationwide panel estimate of −2.1%. We show our "none" grouping with and without Florida because Florida is an outlier with an extremely high proportion of single-family houses in the floodplain (16% compared to a nationwide average of 3.6%). The estimated difference between states requiring all three types of disclosures and states requiring no disclosures is statistically significant ($P < 0.05$) if Florida is omitted from the latter group, but not if Florida is included.

We also find more negative flood zone discounts in communities with high overall exposure to flooding, perhaps because of greater personal experience with flooding or flood risk (*SI Appendix*, Fig. S9 and Table S8). Specifically, in counties with more than 10% of properties in the current floodplain, our estimates are approximately 4 percentage points more negative than in counties with a smaller share of properties in the floodplain. The relative magnitudes and statistical significance of community flood exposure and disclosure law stringency vary across specifications, with disclosure laws appearing more influential with tract-by-year fixed effects and community flood exposure predominating with county-by-year fixed effects. The effects of high community flood exposure and strict disclosure laws are likely to interact in affecting the salience of flood risk to potential buyers. Overall, these results suggest that flood risk awareness, likely due to a combination of disclosure laws and community exposure, shapes the observed flood zone discount.

Second, we observe that more sophisticated commercial buyers discount flood zone properties more heavily (Fig. 4 and *SI Appendix*, Table S9). "Business" buyers, as labeled in our data, range from large corporations that own and rent out single-family homes to family limited liability corporations (LLCs). When businesses purchase flood zone homes, the price penalty of −6.9% (−10.6%, −3.0%) aligns with our estimate of the efficient flood zone discount using a 5% time discount rate. The difference between business and nonbusiness buyers is estimated at −5.1% ($P < 0.01$).

Overvaluation of Floodplain Property. Finally, we combine our empirical results on the flood zone discount with our estimated efficient flood zone discounts to calculate overvaluation of single-family homes in the regulatory floodplain across the United States. Our data contain 3.8 million such properties that represent ∼$993 billion in market value. We repeatedly draw from the distributions of empirical discounts in Fig. 3, generating a range of values for each state. We combine these with our range of estimates of the national efficient flood zone discount, calculate the overvaluation of each floodplain property in our data, and then sum to a national total (*Materials and Methods*). At a 5% time discount rate, we estimate total overvaluation at $43.8

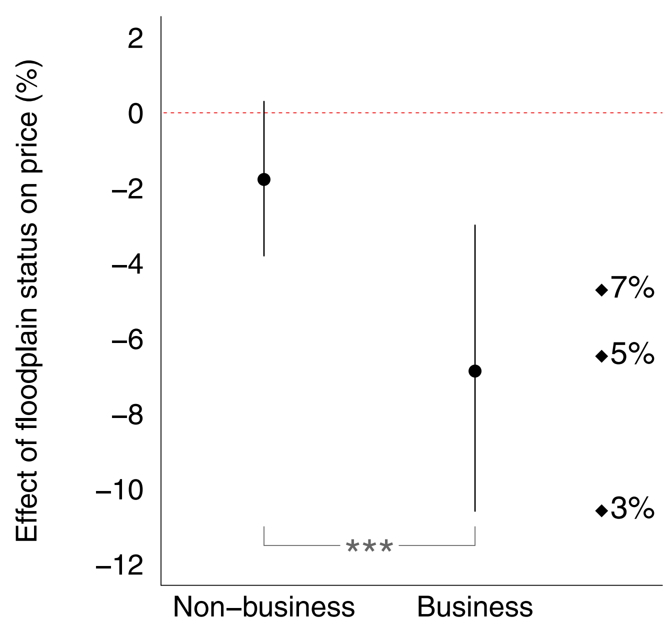

Fig. 4. Businesses discount flood zone properties. The flood zone discount for business buyers is estimated at −6.9%, compared to −1.8% for nonbusiness buyers (n = 5.65 million). Error bars denote 95% confidence intervals, and asterisks denote the statistical significance of differences between groups: ***$P < 0.01$. The diamonds, at right, mark estimates of the efficient flood zone discount under different discount rates.

billion ($32.6 billion, $55.6 billion) (Fig. 5). This range shifts to $26.0 billion ($14.2 billion, $37.7 billion) under a 7% time discount rate and $85.4 billion ($74.1 billion, $97.5 billion) under a 3% time discount rate. This estimate includes only single-family residences in areas with digitally mapped floodplains.

By drawing from a range of values for both the efficient and empirical flood zone discounts, these estimates reflect the possibility that flood zones are not priced at all (or are even beneficial) in many states and that there are numerous factors affecting the efficient discount for any given property. As shown in *SI Appendix*, Figs. S3 and S4, our estimates of the efficient flood zone discount are sensitive to assumptions about insurance prices and related inputs. Uncertainty in the estimates in Fig. 3 also contributes to the overall uncertainty in overvaluation (*SI Appendix*, Fig. S10). As overvaluation is driven by the gap between the efficient and the empirical discount, scenarios with more negative efficient discounts and more positive empirical discounts lead to much larger estimates of floodplain overvaluation.

Discussion

Our findings suggest that many floodplain properties in the United States are overvalued and that development in the floodplain likely exceeds what would be observed if asset prices fully reflected information about flood risk. The additional risk created by these investments is likely growing due to climate change and the long-lived nature of housing and infrastructure. Such concerns extend to other climate hazards as well: Both flood-prone and fire-prone locations have experienced substantial development in recent years (16–18).

The inconsistent pricing of risk in property values may be due to specific features of the real estate market that distinguish it from the theoretical market in which asset prices reflect all relevant information. Real estate transaction costs are high, many of the investors are amateurs (particularly for residential property), and assets are rarely perfect substitutes for one another. In real estate markets, even a fraction of uninformed or optimistic buyers can lead to inflated property valuations because sellers can wait until they receive an offer from that group (19, 20). Surveys have demonstrated the presence of both uninformed and optimistic buyers when it comes to flood risk (12, 21).

Our findings indicate that market efficiency may be improved by enhancing awareness of climate risk among buyers. Awareness and pricing of flood risk are likely shaped by a multitude of factors including buyer-specific features (businesses vs. individuals), community characteristics (overall exposure to flood risk), and regulatory context (real estate disclosure laws). Our results are consistent with other studies of property prices and insurance take-up that show people "learning" and "forgetting" about flood risk over time (22–25). Risk communication efforts can be improved in many ways, such as avoiding portraying flood risk as binary, providing access to information about the extent of past flood events, and through strengthened real estate disclosure laws. Currently, the vast majority of states require disclosures only by the time the contract is signed, which means that very few buyers would know about flood risk before they make their offer. Only two states require that sellers disclose the cost of their insurance policy, which would allow the buyer to evaluate the potential additional cost burden. Broader risk communication efforts could enhance market efficiency and increase insurance take-up, a consistent challenge for the NFIP (26).

We demonstrate that well-informed, sophisticated buyers price the information in the floodplain maps more than a typical buyer, which has also been identified in the pricing of other environmental attributes. For example, sea level rise projections provided by the National Oceanic and Atmospheric Administration have been found to affect property values more in the more sophisticated, nonowner occupied market segment and in areas with high levels of belief in climate change. Those results resonate with ours, although they are difficult to compare directly because we focus exclusively on the regulatory floodplain maps (27). In addition, price capitalization of energy efficiency has been found to increase once disclosure was mandated in real estate transactions (28). Broadly, these results suggest that additional effort to reduce information asymmetry could increase capitalization of flood risk.

The panel and difference-in-difference approaches yield similar estimates of the flood zone discount of −1% to −2%,

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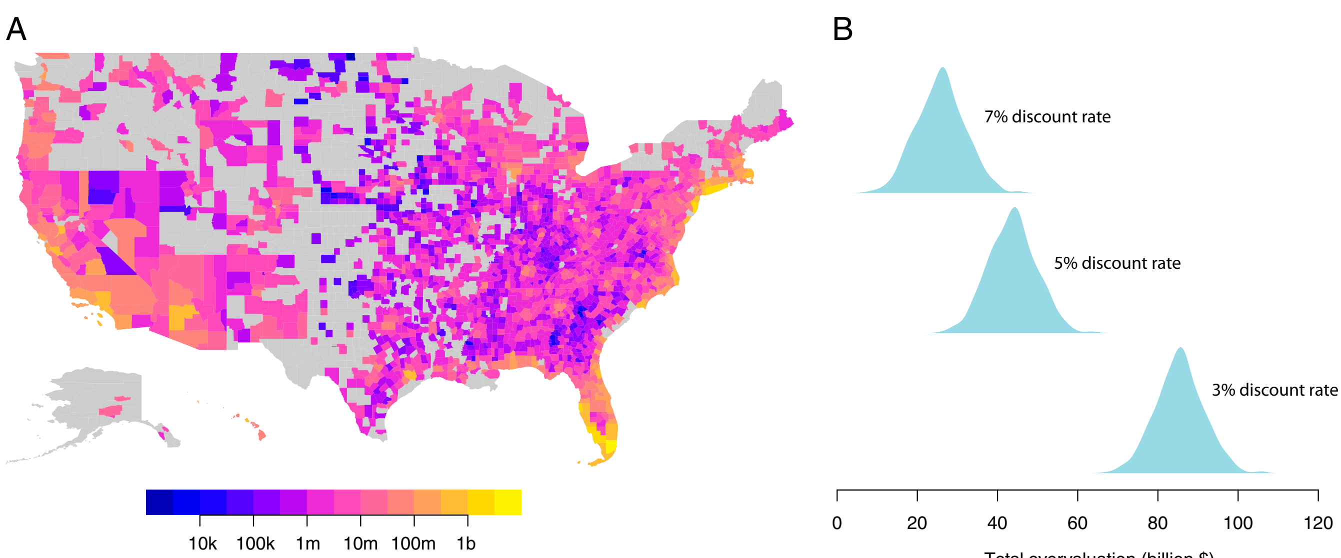

Fig. 5. Floodplain properties across the United States are overvalued. (*A*) County-level totals of estimated overvaluation. Overvaluation is greater in counties with many floodplain properties, high property values, and a large gap between efficient and empirical flood zone discounts. Only counties with a digitized floodplain map covering over 50% of single-family residences are shown in this map. (*B*) Sensitivity of overvaluation estimates to time discount rates. Median estimates range from $26.0 billion under a 7% discount rate to $85.4 billion under a 3% discount rate. The time discount rate affects the efficient flood zone discount estimates (Fig. 2), which in turn affects overvaluation.

while the cross-sectional estimate implies a flood zone bonus for property values. The differences across methods demonstrate that cross-sectional estimates are likely affected by unobserved characteristics that are correlated with both floodplain presence and sale prices. In contrast, because our panel analysis focuses on a single property over time, it allows us to account for all time-invariant characteristics of a home, including its proximity to waterfront amenities. Our panel estimate relies on the assumption that there are no time-varying factors within a county that are correlated with both price and being rezoned into a floodplain, which appears reasonable in our context. Further sensitivity testing, including running three models on the same dataset, shows broadly stable results for the panel and difference-in-difference, while the cross-sectional estimate is much less stable (*SI Appendix*, Table S10).

While our estimates of the effect of the floodplain maps are robust to many specifications, the maps do not capture all forms of flood risk, and they are not the sole source of information available about flood risk. Additional research is needed to better understand the use of local knowledge and the extent to which it diverges from these government-produced floodplain maps. However, given the widespread use of these maps in regulation at local, state, and federal levels and the lack of widely available alternatives, it is likely that these maps are the primary source of information for most market participants. In fact, the larger flood zone discounts we observe in markets with well-informed buyers—discounts in line with what we would expect in an efficient market—provide strong evidence that the floodplain maps are an important source of information. Further, even if certain market participants rely on other sources of information, the influence of the maps themselves is still important to investigate given the substantial public investment they represent.

Our estimates of the flood zone discount and associated overvaluation reflect the information in the floodplain maps and current insurance prices; they do not capture unmapped flood risk, potential future increases in risk due to climate change, or potential future changes in insurance pricing. Changes in insurance pricing would affect our benchmark estimates of the efficient flood zone discount and associated overvaluation. If insurance costs were to increase in the future, the efficient flood zone discount would increase, yielding a larger total overvaluation.

This analysis is limited by several data constraints. The accuracy of our empirical estimates of the flood zone discount is constrained by the accuracy of existing digital floodplain maps and property location data. Property owners can appeal their flood zone designation through a structure-specific elevation study and eliminate their requirement to purchase insurance; such amendments are not recorded in the floodplain maps used in this study. In addition, the spatial resolution of the floodplain maps and location information may lead to some properties near the boundaries being misclassified as inside or outside of the floodplain. More recent map updates, which do not rely on the Q3 data from the 1990s, could yield more precise estimates of the flood zone discount, which would also help reduce uncertainty in our total overvaluation calculations (*SI Appendix*, Fig. S10).

Our estimates of overvaluation of floodplain properties would also benefit from more precise estimates of the efficient flood zone discount. Our benchmarks for the flood zone discount in an efficient market are based on estimates of what full flood insurance coverage would cost. We use NFIP rates because the NFIP dominates the residential flood insurance market, writing over 95% of policies. We estimate unsubsidized rates rather than observed policy premia because only an estimated 30% of floodplain households carry flood insurance, and many of them may be underinsured (29). We do not observe which properties benefit from discounted insurance rates under the NFIP due to the Community Rating System or subsidies. However, legislation to eliminate many NFIP subsidies did not noticeably affect the estimated flood zone discount (*SI Appendix*, Fig. S11), and choices about time discount rates affect the efficient flood zone discount in combination with insurance prices (*SI Appendix*, Fig. S3).

Insurance costs, and by extension the efficient flood zone discount, vary by property and are affected by numerous unobserved or difficult-to-observe characteristics, including elevation relative to base flood elevation, number of floors, wave exposure, and structure value (*Materials and Methods*). We draw on existing NFIP data to inform probability distributions for elevation and other parameters, but insured properties may vary in important ways from the overall distribution. For example, homes owned for multiple generations are unlikely to carry a mortgage that would require carrying flood insurance, and they are also more likely to be at lower elevation given that building codes have generally become more stringent over time. For higher-value properties, estimating the efficient flood zone discount is further complicated by the NFIP's coverage cap of $250,000. We estimate the efficient flood zone discount assuming that coverage could be obtained at the same rate for larger amounts, but those numbers may be underestimates of the true discount for risk-averse buyers who are more concerned about the uninsured portion or who seek private coverage for it at different rates.

Our results demonstrate that markets do not respond uniformly to new information about flood risk; rather, markets with better-informed buyers exhibit stronger responses. These findings point to an opportunity for both researchers and policymakers to identify and implement practices to ensure timely and effective communication of climate risk. These lessons are also relevant to markets beyond real estate where information asymmetries are likely present, as recognized by recent proposals to require corporations to disclose climate risk. Such measures are critical for enabling investments in resilient assets and ultimately limiting damages in a changing climate.

Materials and Methods

Data.

Floodplain maps. For current floodplain maps (officially "Digital Flood Insurance Rate Maps"), we downloaded state-level extracts of the National Flood Hazard Layer (NFHL) from FEMA's Flood Map Service Center in March 2018. The NFHL is a continuously updated digital dataset that represents the current effective floodplain maps for those parts of the country where maps have been digitized. For historical floodplain maps, we obtained Q3 Flood Data, the first digitization of floodplain maps. These were initially produced in 1996 and updated through May 1998. The Q3 data cover 1,289 counties (30).

Each property (and thus each transaction) was overlaid on both the current and historical flood maps and assigned one of three conditions for each time period: in a Special Flood Hazard Area (SFHA) (equivalent to the 1% floodplain), outside of the SFHA, or unmapped.

Dates of map updates. FEMA's floodplain maps are updated sporadically and at various geographic scales, ranging from a portion of a county being updated to multiple counties being updated at once. The current maps include the date they went into effect, so they are taken to be in effect from that date through the download date in March 2018. The Q3 maps are assumed to be effective from 1996. To identify map updates that took place between the Q3 maps and the current maps, we use the FEMA-issued Compendia of Flood Map Changes from 1998 to 2013.

We matched the map updates to properties based on the community or county ID in the Compendium of Flood Map Changes. Earlier floodplain maps were issued by community, which is a subcounty level, and more recent maps have been issued by county. We searched the compendia for updates that matched either a property's community or county and assigned the associated map update date to the property. Because we do not observe exactly which portion of the county map is updated, we conservatively assumed that any map update associated with a county ID affected the entire county.

We have access only to the floodplain maps as published in the Q3 data and the current effective maps. Depending on the frequency of map updates, we observe different portions of a property's floodplain status over time. If a property has never experienced a map update, or if there has been only one update between 1996 and the present, then we observe its floodplain status throughout. If there are multiple updates, for instance in 2004 and again in 2008, then we can use the historical map until 2004 and the current maps from 2008 to the present, but we do not know the property's floodplain status from 2004 to 2008, and any sales during that time are omitted.

Real estate data. Property sales and characteristics data are sourced from CoreLogic, a data vendor which compiles deed transaction records and property tax roll information from US County Assessor and Recorder offices. We included the deed transaction records for all 50 states and the District of Columbia in our analysis. Matching the time period of the flood maps, we included sales beginning in 1997 and ending in 2017.

Transactions missing a parcel identifier, sale price, or location coordinates were removed. We also removed transactions that were part of a split or multiple parcel sale, instances of a parcel transacting multiple times on 1 d, and non–arms-length transactions, such as foreclosures. Transactions were assigned, if possible, to the month and year of the sale date. If transactions were missing a sale date, we used the date that the sale was recorded. If there was no month and year listed for either the sale date or the record date, the transaction was eliminated from the dataset.

Only parcels identified as single-family homes were included in this analysis. Property characteristics such as the year the property was built or substantially renovated, bedrooms, bathrooms, and square footage were also sourced from CoreLogic. These are taken from the most recent tax assessment available, typically 2016 or 2017, and thus reflect approximately present-day property characteristics. We removed sales that occurred before the property's most recent renovation date (the "effective year built") to ensure that the property characteristics apply to the property at the time of sale, and we removed properties with a most recent renovation date before 1968.

Summary statistics for our data are available in *SI Appendix*, Table S2.

Other property characteristics. To obtain the distance from the property to the nearest river, lake, or ocean, we used the US Geological Survey's National Hydrography Dataset (available at https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products). Feature code 566 from the Flowline layer was used to map distance to the coast, feature codes 390 and 493 from the Waterbody layer were used to map distance to the nearest lake or pond, and feature code 460 was used to map distance to the nearest stream or river. We calculated the minimum distance from each property to these water features in R.

Properties were mapped to their corresponding census block group and tract using the US Census Bureau's TIGER/Line shapefiles (available at https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html). The TIGER/Line shapefiles were also used to map the distance from each property to the nearest primary road and secondary road.

Benchmarks for the Flood Zone Discount.

Efficient market discount. We estimate the efficient flood zone discount as the difference between a flood-prone and otherwise identical safe property, reported as a fraction of the value of the safe property. We use the present cost of fully insuring the home against flood damage to approximate the difference between the flood-prone and otherwise identical safe property,

$$FZD = \frac{\sum_{t=0}^{\infty} \frac{P}{(1+r)^t}}{V}$$

where P represents the annual premium, r is the discount rate, and V is the total value of the otherwise-equivalent safe property.

P is a function of coverage amount, deductible, property elevation, and other property characteristics. To most closely approximate the efficient flood zone discount, we assumed that the households are fully insured with the lowest possible deductible of $1,250 and that the insurance coverage is equal to the value of the structure, such that there would be minimal uninsured costs. We compare here against a house with no flood insurance costs since it has been estimated that only 1% of nonfloodplain houses are insured (31). However, the efficient flood zone discount would be smaller if we were to assume that the nonfloodplain house option included nonzero costs.

A key input to our estimates is the market value of floodplain property. Current market values are available only for properties that have sold in the recent past. To generate a complete set of market values, we start with the maximum value in tax roll data across three reported property value columns: "assessed total value," "market total value," and "appraised total value." The completeness of these fields varies, but at least one value is available for over 99% of floodplain properties, and they generally date from either 2016 or 2017. However, these values can diverge substantially from sale prices. Therefore, for each state's sales since 2014, we calculate the ratio of sale price to reported property value from the tax data and then extract the median ratio. We then scale our reported values to an estimated market value using this factor. For example, if the median transaction price since 2014 is 5% larger than the reported property value, we multiply all reported property values by 1.05 to obtain our final estimated market values. With the exception of one state, these scaling factors fall between 0.95 and 1.4.

To account for uncertainty in the other parameters affecting the premium, we repeatedly sample from a set of parameter distributions. We start by drawing a sample of 10,000 floodplain houses from our parcel data, each with an estimated current market value, flood zone, and state. We include only properties with market values between $50,000 and $5 million. We also draw an empirical estimate of the flood zone discount for each state based on the distributions in Fig. 3. Then, the following process is undertaken for each sampled house using three different time discount rates of 3%, 5%, and 7%:

1) The market value is split into land and structure values by drawing a value from the Lincoln Land Institute's data on land and property values. The national average of the percentage of property value attributed to land is calculated for each year from 1998 to 2016, and one value is drawn at random from this pool. The values range from 20% (2011) to 37% (2006), so we attribute somewhere from 63 to 80% of the observed market value to the structure.
2) The present cost of insurance premia to cover the full structure value is estimated. Following ref. 7, these are based on the April 2016 NFIP Flood Insurance Manual for post-FIRM properties. The flood zone (wave-exposed V zone or A zone) is drawn directly from the parcel data. Property characteristics including elevation, number of floors and basement, presence of obstructions for coastal properties, and replacement cost to value ratio are drawn from a set of probability distributions. FEMA's dataset on insurance policies was used to inform the distributions of these parameters, although the set of properties carrying insurance may systematically differ from the overall distribution of floodplain properties. The distribution of input parameters is shown in *SI Appendix*, Table S12.
3) Because the flood zone discount represents the difference between a flood-prone and an otherwise "safe" home, we estimate the market value of the property were it not in a floodplain using the empirical estimate of the flood zone discount. For our estimate of the efficient flood zone discount, we then divide the present cost of a stream of insurance payments by this safe value.

We calculate the median flood zone discount across the 10,000 sampled houses. We then repeat this process 500 times, drawing a new random sample of 10,000 houses each time, yielding 500 estimates of the efficient flood zone discount for the nation for each of the three discount rates used. The median of each distribution is shown as the black diamond in Fig. 2. These values are then used as input into our overvaluation calculation below.

Present value of insurance. Numerous past studies report data on housing prices and the average insurance premium in the study location. To estimate the price penalty associated with the insurance costs in these study locations, we calculated the present value of a stream of insurance payments, again using three different discount rates of 3%, 5%, and 7%, and divided by the average sale price. These studies do not always report important characteristics of the insurance prices, such as whether houses tend to underinsure and whether any of the properties benefit from subsidized insurance prices. For those reasons among others, these estimates may diverge from our estimates of the efficient flood zone discount.

Empirical Approaches. We implemented three different empirical approaches to estimate the flood zone discount: panel repeat sales, difference-in-difference, and cross-sectional.

Panel repeat sales. This method identifies the effect of floodplain status on property value by comparing a single property to itself over time, as its flood zone status (*FP*) can change as the floodplain map is updated. We estimate the regression

$$log(p_{icat}) = \delta FP_{iat} + \gamma_i + \mu_{ca} + \eta_{ct} + \epsilon_{icat},$$

where FP_{iat} is a binary variable equal to 1 if the property *i* of age *a* is in the floodplain at the time of sale *t*, and 0 otherwise. δ is the estimated effect of being in the floodplain on prices (p_{icat}). The property fixed effect, γ_i, accounts for time-invariant confounds including property characteristics, such as proximity to water. We also include fixed effects for the age of the property at sale by county μ_{ca} and for county–year η_{ct}. The former ensures that we are comparing houses of the same age within a given county, and the latter flexibly absorbs local market trends. In our main specifications, errors are clustered by county; results in *SI Appendix* include errors clustered by county and by year.

The key assumptions for this approach are twofold. First, we assume that, after accounting flexibly for time trends or shocks at the county level, any remaining time-varying unobservables are not correlated with both rezoning into the floodplain and price. Second, we assume that the values of time-invariant characteristics that are correlated with rezoning into the floodplain, such as proximity to the coast, are not changing over time. In additional robustness tests, we include census tract-by-year fixed effects and allow for properties at different proximity to water and in different price tiers to experience different time trends (*SI Appendix*, Fig. S5). Time series plots showing price trends relative to the timing of map updates are included in *SI Appendix*, Fig. S12.

To be included in the panel sample, a property must be outside of the floodplain in the old map, it must have a known floodplain status in the new map, and it must be sold more than once while its floodplain status is known. Sales that occur while the floodplain status is unknown are dropped from the dataset. The treated properties are those that are sold after being zoned into the floodplain when the map is updated. We filter for outliers by removing properties that exhibit more than 50% annual growth or decline in sale price between observed transactions. Inclusion of these outliers does not affect our results, yielding an estimated flood zone discount of −2.2% rather than −2.1%.

We note that estimates of δ could reflect decreases in demand for floodplain properties, increases in demand for nonfloodplain properties, or some combination of the two. Distinguishing these two effects is not possible in our design, nor is it critical to our research question, which is in understanding the difference in price between a floodplain home and an otherwise identical safe home. That difference should capture both reduced value due to being in a floodplain and increased value due to not being at risk.

Difference-in-difference. Similar to the panel approach, the difference-in-difference strategy uses a map update that zones certain houses into the floodplain to measure the impact of floodplain status on property value. However, it does not require that a single parcel is sold more than once during the observational period. Instead, we compare two properties within the same county or census tract, where both begin outside of the floodplain and one house is then zoned into the floodplain. We assume that absent the floodplain map changing, prices would trend similarly between the two properties. Pre- and posttreatment price trends are shown in *SI Appendix*, Fig. S13. Our estimating equation is the following:

$$\begin{aligned} log(p_{icqst}) = \beta_1 NewFP_i + \beta_2 NewMap_{it} \\ + \delta NewFP_i * NewMap_{it} + \lambda_s \mathbf{Z}_{it} \\ + \eta_{ct} + \alpha_{sq} + \epsilon_{icqst}. \end{aligned}$$

δ is the effect of being zoned into the floodplain on prices. $NewFP_i$ is a binary variable equal to 1 if the property is located in the new floodplain, regardless of whether the old or the new flood map is in effect at the time of sale. β_1, the coefficient on $NewFP_i$, represents the premap change difference between property values in the two regions. $NewMap_{it}$ is a binary variable equal to 1 if the sale occurs after the map has been updated, and its coefficient β_2 represents any change in property values common to both regions that occurred after the map was updated. The estimation is at the property level because different locations experienced map changes at different times. As with the panel method, errors are clustered at the county level in the main specifications, with clustering by county and by year shown in *SI Appendix*.

To account for differences in the composition of houses sold at different times, we flexibly adjust for a number of property-specific characteristics in $\mathbf{Z}_{it}$: age of property at the time of sale, land area, living area, and number of baths (all binned), as well as geographic characteristics: census tract, distance to coast, river, lake, primary road, and secondary road. All of the distance variables are binned at 0 to 100 m, 100 to 500 m, 500 m to 1 km, 1 to 2 km, 2 to 3 km, 3 to 4 km, 4 to 5 km, and for coast and road distances, 5 to 10 km, and greater than 10 km. All property characteristics are included as state-by-characteristic fixed effects, which allows their value to vary nonlinearly across bins and across states. α_{sq} is a fixed effect for the quarter of sale by state to account for seasonal market changes, and η_{ct} is again a fixed effect for each county–year, which flexibly absorbs local market trends. We also implement this model with census tract–year fixed effects, shown in *SI Appendix*, Fig. S6.

To be included in the sample for this method, a property must be outside of the floodplain in the old map, its floodplain status must be known in the new map, and the switch from the old map to the new map must be a direct change. The switch from old to new is not always a direct change because some places have a map version we do not observe that was in effect between our old map and our new map. We drop these observations from our sample. In addition, we remove outliers by filtering the highest- and lowest-priced 1% of sales from each county.

As an additional measure to maximize the similarity between control houses and rezoned houses, we test our results when limiting the data to only counties or census tracts with houses rezoned into the floodplain. Our primary estimates use a time period of 10 y on either side of the map update. We test the sensitivity to shorter time windows as well. Results of these sensitivity tests are shown in *SI Appendix*, Fig. S6.

Cross-section. To compare to earlier estimates in the literature, we implement a cross-sectional analysis that decomposes the sales price into property characteristics, location characteristics, and floodplain presence. This approach pools all sales for which the floodplain status is known. To estimate the flood zone discount, this method relies on the (in our view unlikely) assumption that we have controlled for every property characteristic that is correlated with floodplain status and price:

$$log(p_{icqst}) = \lambda_s \mathbf{Z}_{it} + \delta FP_{it} + \eta_{ct} + \alpha_{sq} + \epsilon_{icqst}.$$

$\mathbf{Z}_{it}$ is a vector of property characteristics identical to the one described in the difference-in-difference section, and these are again incorporated as state-by-characteristic fixed effects. δ is once again the effect of being in the floodplain on property prices. Errors are clustered at the county level.

All sales when the floodplain status of the property is known are included in the cross-sectional regressions. We remove outliers by filtering the highest- and lowest-priced 1% of sales from each county.

Real Estate Disclosure Laws. To explore the relationship between the flood zone discount and real estate disclosure laws, we run our panel regression with an interaction term D_s:

$$log(p_{icast}) = \delta_1 FP_{iat} + \delta_2 (FP_{iat} * D_s) + \gamma_i + \mu_{ca} + \eta_{ct} + \epsilon_{icast}.$$

Real estate disclosure laws vary widely in what they address, how they are implemented, the required timing of disclosure, and the consequences for failure to disclose. To simplify these many dimensions, we consider three common types of flood-related disclosures:

- Floodplain location. These disclosures ask whether the property is located in the floodplain or ask for the flood zone designation of the property.
- Flood damage. This disclosure type includes any disclosures about drainage, leakage, water intrusion, standing water, and flooding problems, both past and present.
- Flood insurance. This disclosure type includes whether flood insurance is currently carried on the property, whether it is required to be carried, whether claims have been made recently, and the cost of insurance.

D_s is a categorical variable with levels 0 to 3 representing the number of types of disclosures covered in that state. We use a time-invariant value (representing the current requirements) because although state real estate disclosures vary over time, the changes over time are difficult to track. Some states give a real estate association authority to create a mandatory disclosure form, but the content of the form can change without any legislative action. We treat disclosures as mandatory even if sellers can avoid them in certain instances, such as by paying a fee (Connecticut and New York) or by filing a disclaimer form rather than a disclosure form (Maryland).

The inventory of state real estate disclosure laws was compiled based on information from the Natural Resources Defense Council and the National Association of Realtors (32, 33).

Business Buyers. We test whether business buyers respond to the floodplain designation differently than individuals and couples by modifying our panel regression to include an interaction term:

$$log(p_{icat}) = \delta_1 FP_{iat} + \delta_2 (FP_{iat} * B_{iat}) + \rho B_{iat} + \gamma_i + \mu_{ca} + \eta_{ct} + \epsilon_{icat}.$$

B_{iat} is equal to 1 if the buyer is marked as a business buyer and is zero otherwise. Buyers are defined by CoreLogic as either a business or an individual/couple. The determination is based on the name; for instance, all buyers ending in "LLC" are tagged as businesses. As a result, family LLCs or family trusts are typically designated as businesses. The business designation also captures other organizations that are not businesses, such as nonprofits and government agencies. However, all of these buyers—whether a family with an LLC, a large corporation, or a nonprofit—are likely to be better resourced than a typical individual or couple purchasing a home.

Overvaluation. To estimate current overvaluation of houses in the floodplain, we calculate the difference between the current market value of floodplain homes and the values we would expect under an efficient market. This process builds directly on the steps described in *Benchmarks for the Flood Zone Discount*, which produces 500 estimates of the national efficient flood zone discount under three different discount rates. Each of the efficient flood zone discount estimates is based on a draw of state-specific values for the empirical discount, which are based on results in Fig. 3.

We start with the estimated current market value for floodplain single-family homes in our dataset. For each of 500 runs, we repeat the following process:

1) Assign the empirical flood zone discount for that state to the property.
2) "Undiscount" the current market values for each property based on the discount drawn in the previous step. This value approximates the market value of the otherwise equivalent safe property.
3) "Rediscount" each property using the efficient flood zone discount to approximate the efficient market value.
4) Calculate the difference between the current market values and the efficient market values for each property.
5) Sum the overvaluation amounts for each county and scale to reflect any floodplain properties in the county that do not have market value data. Less than 1% of floodplain properties in our data are missing market values.

This process yields 500 estimates of overvaluation. We generate these estimates under time discount rates of 3%, 5%, and 7%.

As an example, suppose we have a property with an observed market value of $1 million, and our estimate of the empirical discount is 2% and the efficient discount is 5%. Then the estimated efficient market value from steps 1 to 3 is $1 million/(0.98) * (0.95) = $0.969 million, and the overvaluation from that property in step 4 is $31,000.

Data Availability. Property records cannot be released under the data use agreement with CoreLogic. All other supporting data and replication code are available at https://purl.stanford.edu/td021fz7393.

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