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ABSTRACT

Floods and other climate hazards pose a widespread and growing threat to housing and infrastructure around the world. By incorporating climate risk into asset prices, markets can discourage excessive development in hazardous areas. However, the extent to which markets actually price these risks remains poorly understood. Here we measure the effect of information about flood risk 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 US, we find little evidence that housing markets fully price information about flood risk in aggregate. However, the price penalty for flood risk is larger for commercial buyers and in states where sellers must disclose information about flood risk to potential buyers, suggesting that policies to improve risk communication could influence market outcomes. Our findings indicate that floodplain homes in the US are currently overvalued by a total of $34B, raising concerns about the stability of real estate markets as climate risks become more salient and severe.

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1 Introduction

Global economic losses from natural hazards have increased nearly ten-fold since the 1970s, with the United States experiencing $300 billion in losses in 2017 alone [Bouwer, 2011, Swiss RE, 2019, NCEI, 2019]. This trend is primarily driven by an increase in the number of people and amount of wealth concentrated in locations at risk from tropical cyclones, floods, and other hazards [IPCC, 2012]. Managing development in risky 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 properties, 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 >1% chance of flooding in any given year, referred to as the Special Flood Hazard Area or the "floodplain." These Flood Insurance Rate Maps 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 $100M annually for floodplain mapping activities, with FY2018 funding of $262.5M [115th Congress, 2018, Congressional Budget Office, 2017]. 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 [Kousky et al., 2016].

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 [Beltrán et al., 2018]. This large range likely reflects the narrow geographic scope of past work, with individual estimates often based on data from a single county or city (Figure 1). In addition, 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. Of the few non-cross sectional studies, results are mixed: in Centre County, PA, rezoning *into* a floodplain reduced property values, but rezoning *out of* a floodplain had no effect [Shr and Zipp, 2019]. 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 Hurricane Sandy [Gibson et al., 2019].

Here we conduct the first nationwide evaluation of the effect of floodplain presence on property values, which we refer to as the "flood zone discount." We construct a novel timeseries of floodplain maps by gathering CDs 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 (Figure S1). In addition, the maps are updated at different times around the country (Figure S2) based on factors including the age of the current floodplain map, the amount of population and assets located in the area, recent rates of development, and availability of new data [National Research Council, 2009].

We combine these changes in floodplain maps with detailed proprietary data on the universe of real estate transactions in the US to implement three methods for estimating the flood zone discount: panel, difference-in-difference, and cross-section. 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 non-floodplain 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.

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 pre-date 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. 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. These maps are the only nationwide, publicly-available source of information on flood risk, and they have been shown to positively affect voluntary insurance purchase [Shao et al., 2017].

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 [Chivers and Flores, 2002]. 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 [Troy and Romm, 2004]. We study two 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.

2 Data and empirical approach

2.1 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.

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 until the present. 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 1998-2013.

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 sub-county 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 within the county affected the entire county.

We only have access 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 2004-2008 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 U.S. 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 1996 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 one day, 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 data set.

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 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 either unknown or before 1968.

Summary statistics for our data are available in Table S2. Property records cannot be released under the data use agreement with CoreLogic.

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[1]. Feature code 566 from the Flowline layer was used to map distance to the coast, features codes 390 and 493 from

[1]Available at `https://www.usgs.gov/core-science-systems/ngp/national-hydrography/access-national-hydrography-products`

the Waterbody layer were used to map distance to the nearest lake, 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[2]. The TIGER/Line shapefiles were also used to map the distance from each property to the nearest primary road and secondary road.

2.2 Benchmarks for the flood zone discount

Efficient market discount We estimated the efficient flood zone discount as the present value of a future stream of insurance payments as a fraction of the home's total value:

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

where P represents the annual premium, r is the discount rate, and V is the total value of the home. National Flood Insurance Program premia depend on numerous factors, including the elevation of the home, if it has a basement, and whether or not it is exposed to waves. We used data on insurance premia from Kousky et al. for houses that are not exposed to waves, built at or two feet above base flood elevation, and have at least two floors with no basement [Kousky et al., 2016]. These policies approximate a lower bound for non-subsidized insurance costs as premia are substantially higher for houses exposed to waves and at lower elevations. While many communities now have building codes that require floodplain properties to be constructed at or slightly above the base flood elevation, many older buildings are lower.

We considered households insuring for either $250,000 or $125,000 of coverage. 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 calculated the total property value V based on the structure value. On average in the US in 2016, the structure comprised 71% of the total home value, with land making up the remaining 29% [Lincoln Institute of Land Policy, 2016]. We then averaged our four estimates of the flood risk discount: for coverage amounts of $250,000 and $125,000, at elevations equal to and two feet above the base flood elevation. We repeated this process under three discount rates r of 3%, 5%, and 7%.

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

[2] Available at `https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html`

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 under-insure and if 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.

2.3 Empirical approaches

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

Our first method, panel repeat sales, identifies the effect of floodplain status on property value by comparing a single property to itself over time, as its flood zone status (FP_{it}) can change as the floodplain map is updated. We estimate the following regression:

$$log(p_{ict}) = \delta FP_{it} + \gamma_i + \mu_c Age_{it} + \eta_{ct} + \epsilon_{ict}$$

where δ is the estimated effect of being in the floodplain on prices (p_{ict}). FP_{it} is a binary variable equal to 1 if the property is in the floodplain at the time of sale, and 0 otherwise. The property fixed effect, (γ_i), accounts for the time-invariant confounds including property characteristics, such as proximity to water. We also control for the age of the property at sale by county. η_{ct} is a fixed effect for each county-year (c and t), which flexibly absorbs local market trends. Errors are clustered by county in all specifications.

The key assumptions for this approach are two-fold. First, we assume that, after accounting flexibly for time trends or shocks at the county level, that any remaining time-varying unobservables are not correlated with both rezoning into the floodplain and price. Second, we assume that the value 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 (Figure S3).

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 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 estimating flood zone discount of -2.2% rather than -2.1%.

Similar to the panel approach, our 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 post-treatment price trends are shown in Figure S4. 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 new flood map is in effect at the time of sale. β_1, the coefficient on $NewFP_i$, represents the pre-map 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.

To account for differences in the composition of houses sold at different times, we flexibly account 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 0-100 m, 100-500 m, 500 m-1 km, 1 km-2 km, 2 km-3 km, 3km-4km, 4 km-5 km, 5 km-10 km, and greater than 10 km. 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 Figure S5.

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 control group to only houses in counties or census tracts with rezoned houses. Our primary estimates use a time period of ten years 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 Figure S5.

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 spatial difference-in-difference section. 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.

2.4 Estimating heterogeneous effects

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:

$$log(p_{ict}) = \delta_1 FP_{it} + \delta_2 (FP_{it} * B_{it}) + \rho B_{it} + \gamma_i + \mu_c Age_{it} + \eta_{ct} + \epsilon_{ict}$$

B_{it} 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 a 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 non-profits and government agencies. However, all of these buyers — whether a family with an LLC, a large corporation, or a non-profit — are likely to be better-resourced than a typical individual or couple purchasing a home.

Real estate disclosure laws 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 if 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, if it is required to be carried, if claims have been made recently, and the cost of insurance.

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

$$log(p_{icst}) = \delta_1 FP_{it} + \delta_2(FP_{it} * D_s) + \gamma_i + \mu_c Age_{it} + \eta_{ct} + \epsilon_{icst}$$

where D_s is a categorical variable with levels 0-3 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 [NRDC, 2018, NAR, 2019][3].

2.5 Overvaluation

To estimate current overvaluation of houses in the floodplain, we compare our estimates of the observed floodplain discount to the efficient flood zone discount under a 5% discount rate. We sum the total assessed value of houses in the floodplain from across the United States. Assessed values are available for over 98% of the floodplain houses in our data, and they date from either 2016 or 2017. For each state, we obtain "undiscounted" values by treating observed values as currently discounted by the results in Figure 3. Then, we re-discount with the efficient value (-6.9%, based on a 5% discount rate) and take the difference between the observed values and efficient values. Our estimate serves as a lower bound as sale prices frequently exceed assessed values.

[3]Available at https://www.nrdc.org/flood-disclosure-map and https://www.nar.realtor/sites/default/files/documents/2019_State_Flood_Disclosures_Table_final.pdf

3 Results

3.1 Pooled sample

Across the universe of single-family home sales in the US, we find in our preferred panel specification (n = 5.65M sales) that being zoned into the floodplain reduces property values by -2.1% (95% CI of [-4.9%, 0.8%]) (Figure 2). The difference-in-difference estimate (n = 5.64M) is similar at -1.4% [-3.0%, 0.2%], while the cross-sectional estimate (n = 17.6M), which is again unlikely to represent an unbiased estimate of the flood zone discount, is positive at 1.7% [0.6%, 2.8%].

To provide context for these estimates, we compare our results to two different benchmarks. First, we benchmark against estimates of the present value of a future stream of insurance costs as a percentage of total property value, using 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% (Figure 2, blue lines).

However, the present value of insurance costs may not equal the full pricing of presence in the floodplain. We aim to estimate the present value of expected flood damages to the property, and insurance costs may not equal the expected flood damage if households are under-insured or if the policy carries a large deductible. Accordingly, as our second benchmark, we use data on insurance prices from the NFIP to estimate expected flood damage: we assume that houses are fully insured with the minimum deductible, such that virtually all the costs from flooding would be covered by the insurance policy. Using this approach, we estimate that full pricing of presence in the floodplain would affect property values by -5.1% to -10.7%, depending on the discount rate (Figure 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.

To test the robustness of our results, we examine several aspects of the rezoning 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 FEMA's initial maps [Pralle, 2019, Davis, 2010]. 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 (Figure S3).

Second, 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 observed in our data). We evaluate this possibility using the difference-in-difference specification to test if the flood zone discount emerges earlier in time than the official flood map update. If we assume the new information is released two years prior to the official date, our central estimate shrinks from -1.4% to -0.7%. Given 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 [Chivers and Flores, 2002].

3.2 Access to information

While aggregate nationwide results show little evidence that information about flood risk is fully priced in property markets, we find much stronger evidence that markets with better-informed buyers discount floodplain properties relative to safer properties.

First, evidence for a flood zone discount is strongest in states with strict real estate disclosure laws concerning flood risk (Figure 3). States have adopted widely 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 if flooding has ever been experienced, the flood zone classification (and the source and date of the information), if there is flood insurance on the property, if the seller has a flood elevation certificate, if the seller or previous owner received any form of federal flood assistance, and if 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. We find the strongest evidence of a flood zone discount in states requiring all three types of disclosures. In those strict states, the estimated flood zone discount is -4.1% [-7.3%, -0.7%], compared to our nationwide average of -2.1%. None of the other groupings offer strong evidence of a flood zone discount, but our central estimates do become more negative with additional disclosure laws when Florida (which has a very high share of properties in the floodplain) is omitted from the "no disclosure" grouping.

Second, we observe that more sophisticated commercial buyers also discount flood zone properties (Figure 4). "Business" buyers, as labeled in our data, range from large corporations that own and rent out single-family homes to family LLCs. When businesses purchase flood zone homes, the price penalty of -6.9% [-11.7%, -1.7%] aligns with our estimate of the efficient flood zone discount using a 5% discount rate. On the other hand, when non-business buyers purchase flood zone homes, we estimate a flood zone discount of -1.8% [-4.4%, 1.0%].

Our findings indicate that there are at least 3.8M floodplain homes in the US, assessed at nearly $700B in total, that are discounted in practice by anywhere from -0.6% to -4.0% (Figure 3). To estimate the total overvaluation of these homes, for each home we calculate the difference between the efficient flood zone discount (which we set at -6.9%, our average estimate at a 5% discount rate) and the estimated discount in each home's disclosure-based state groupings in Figure 3. Based on assessed property values in 2016 and 2017, we estimate that these floodplain homes are overvalued by a total of $34B. This estimate is very likely a lower bound because it relies on assessed values that are often much lower than sale prices (and missing for about 1% of properties), and because it does not include the small fraction of properties in communities that rely on paper maps.

4 Discussion

Our findings suggest that many of the 3.8 million floodplain homes in the US are over-valued 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 [Lazarus et al., 2018, Radeloff et al., 2018, Climate Central and Zillow, 2018].

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 [Glaeser and Nathanson, 2015, Pope, 2008]. Surveys have demonstrated the presence of both uninformed and optimistic buyers when it comes to flood risk [Chivers and Flores, 2002, Bakkensen et al., 2017]. Accordingly, we find that markets with better-informed and sophisticated buyers exhibit stronger evidence of an efficient flood zone discount, which is consistent with pricing of other environmental attributes such as exposure to sea level rise [Bernstein et al., 2019, Myers et al., 2019].

Our findings indicate that market efficiency may be improved by enhancing communication of climate risk to buyers, for instance through stricter real estate disclosure laws or by directly communicating flood risk information to buyers early in their search process. Studies have found that severe floods and storms that bring attention to these risks can trigger price adjustments, even in areas that were not damaged by the flood event [Bin and Landry, 2013, Hallstrom and Smith, 2005, Kousky, 2010]. The vast majority of states currently only require disclosures 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 the seller disclose the cost of their insurance policy, which would allow the buyer to evaluate the additional cost burden.

The panel and difference-in-difference approaches yield similar estimates of the flood zone discount of -1 to -2%, while the cross-sectional estimate implies a flood zone bonus for property values. The differences across methods demonstrates that cross-sectional estimates are likely affected by unobserved characteristics that are correlated with both floodplain presence and property value, preventing us from isolating the flood zone discount. 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.

While our estimates of the effect of the floodplain maps are robust to many specifications, it is theoretically possible that real estate markets are responding to a different measure of flood risk than what these public maps provide. Given the widespread use of the government-produced floodplain maps in regulation at local, state, and federal levels and the lack of widely available alternatives, the use of other measures of flood risk seems unlikely. 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. Additional research is needed to better understand the use of local knowledge and the extent to which it diverges from the floodplain maps.

This analysis is limited by several data constraints. First, our benchmarks for efficient market pricing are based on data available on NFIP insurance premia. It is possible that buyers are insuring at lower rates, which would explain a smaller flood zone discount. The NFIP dominates the residential flood insurance market, and it has generally been found to be comparable or less expensive than private sector alternatives [Kousky et al., 2016]. While certain properties do benefit from subsidized insurance rates under the NFIP, policies to eliminate those subsidies were implemented in 2012 and in 2014, and the flood zone discount has remained steady during that time period (Figure S6). Another data constraint stems from 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 mis-classified as inside or outside of the floodplain.

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.

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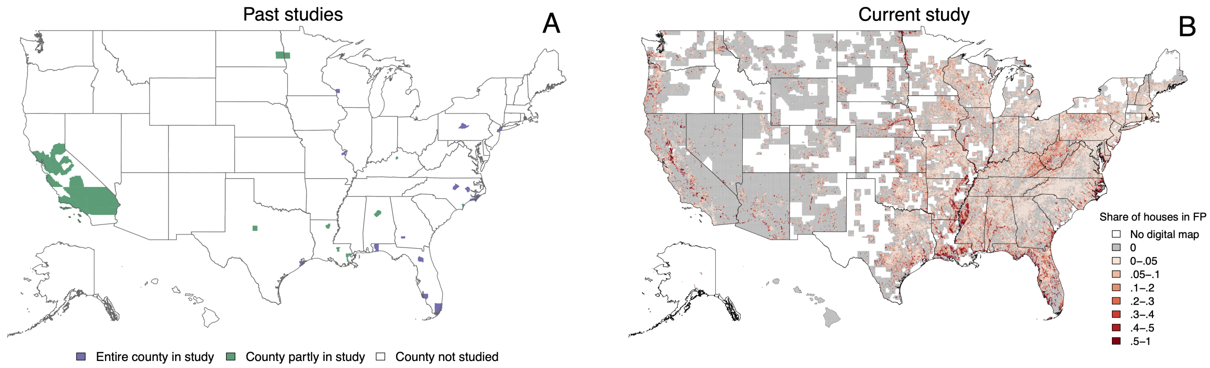

Figure 1: Geographic coverage of studies of the flood risk discount in the US. (A) Locations of past studies. Existing studies have typically evaluated a single county or city at a time. Sources included are listed in Table S1. (B) Geographic coverage of data used in this study, mapped on a 5 km by 5 km grid. The areas in white do not have a digitized floodplain map. Darker shades of red indicate a higher proportion of single-family homes in the floodplain within the grid cell. Over 3.8M single-family homes are currently located in the floodplain.

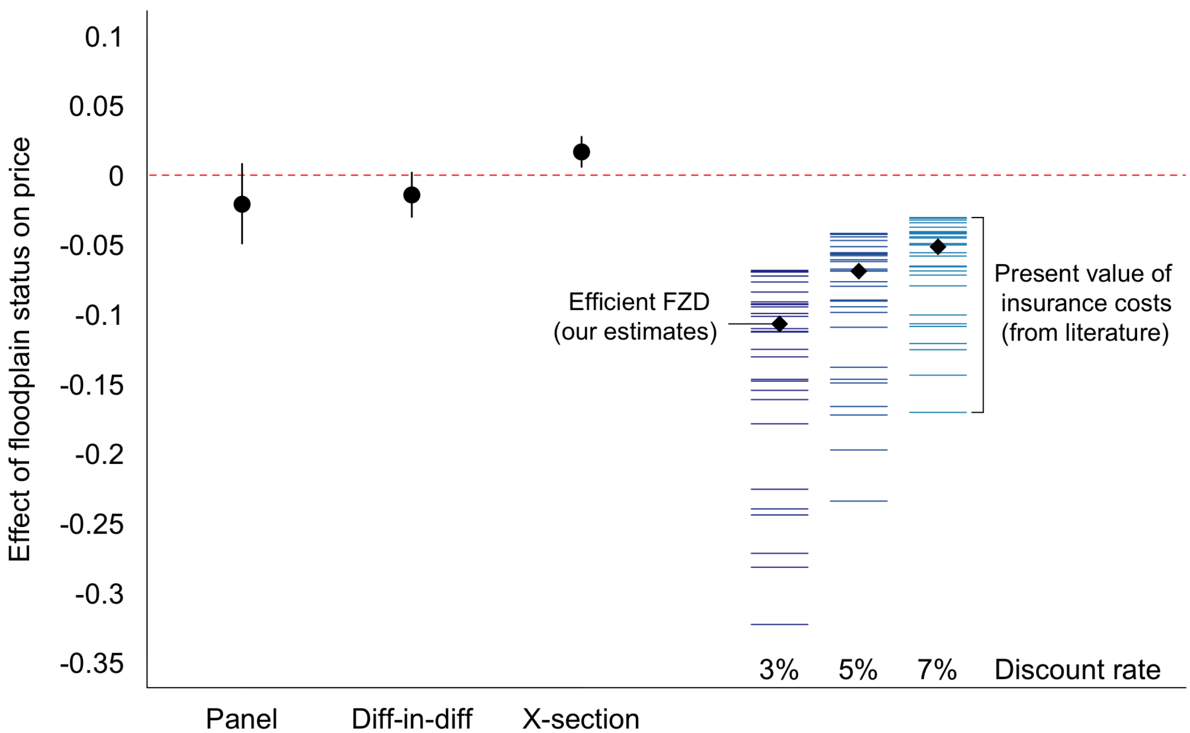

Figure 2: Information about flood risk is not fully reflected in property values. The results of each method are shown at left, with error bars marking 95% confidence intervals (n from left to right: 5.65M, 5.64M, 17.6M). At right, the diamonds denote our estimates of the efficient flood zone discount, 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.

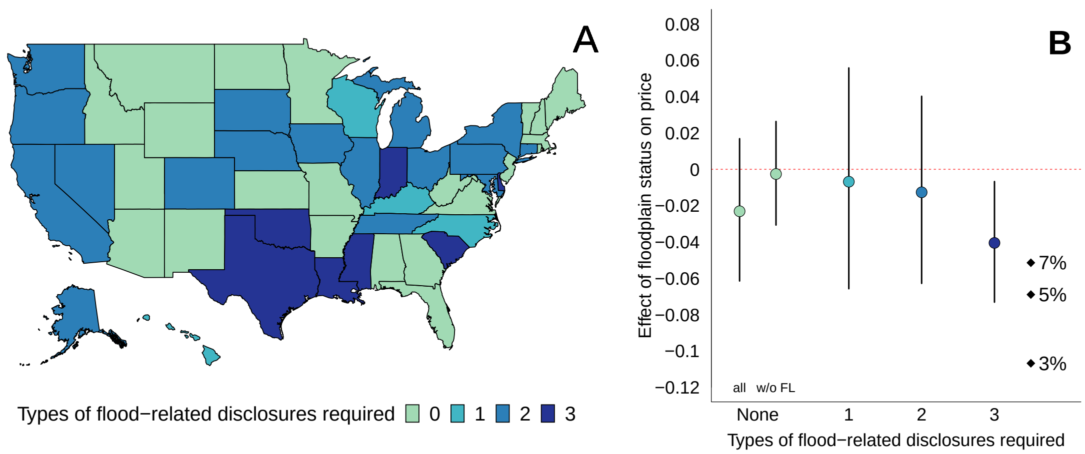

Figure 3: The flood zone discount appears larger in states with very strict real estate disclosure laws concerning flood risk. (A) The types of flood-related real estate disclosures required in each state. Three types of disclosures are considered: floodplain location, flood damage, and flood insurance. (B) Estimates of the flood zone discount based on the types of flood-related real estate disclosures required ($n = 5.65$M). States are grouped based on coloring in (A). Error bars denote 95% confidence intervals.

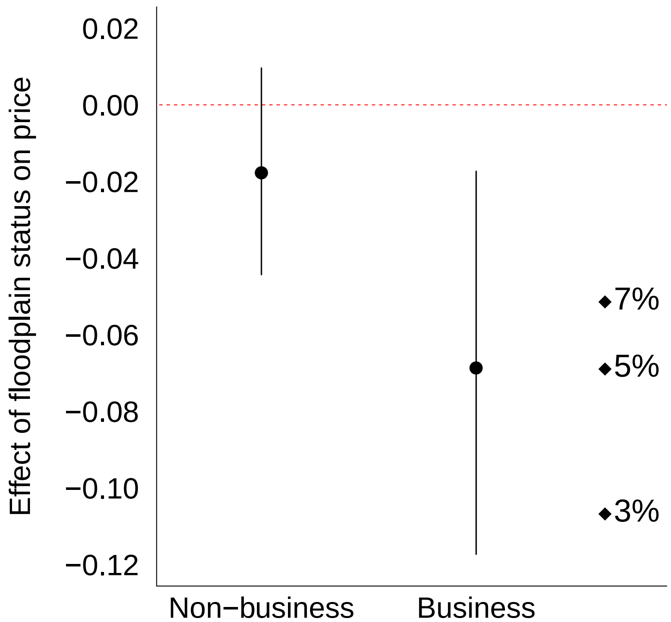

Figure 4: Businesses discount flood zone properties. The flood zone discount for business buyers is estimated at -6.9%, compared to -1.8% for non-business buyers ($n = 5.65$M). Error bars denote 95% confidence intervals. The diamonds, at right, mark estimates of the efficient flood zone discount under different discount rates.

Appendix

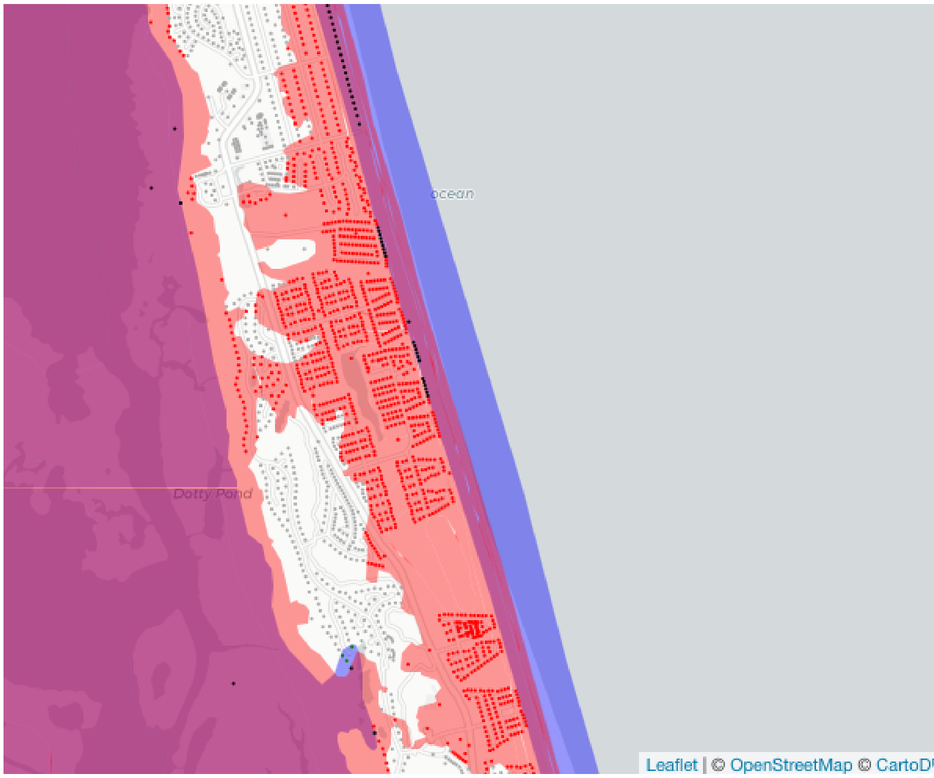

Figure S1: Spatial variation in old and new floodplain maps. Dots represent parcels in our dataset and are shaded based on their floodplain status under the old and new floodplain maps. The floodplain in the old map is shaded blue, and the floodplain in the new map is shaded red. Purple areas and black dots are in the floodplain under both maps. Parcels that remain outside of the floodplain in both time periods (our control properties) are gray. Parcels rezoned into the floodplain (our treatment properties) are red.

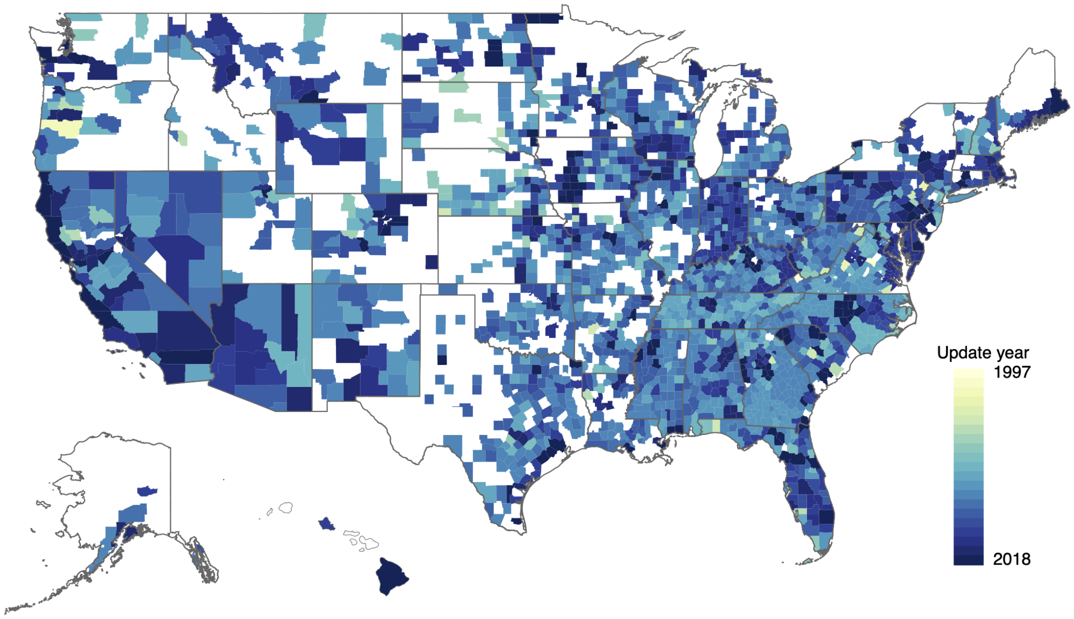

Figure S2: Temporal variation in floodplain map updates. Color indicates the year of the newest effective map in the county, based on maps produced at the county level (with DFIRMs ending in "C"). Areas in white are home to sub-county level maps or do not have a digital floodplain map.

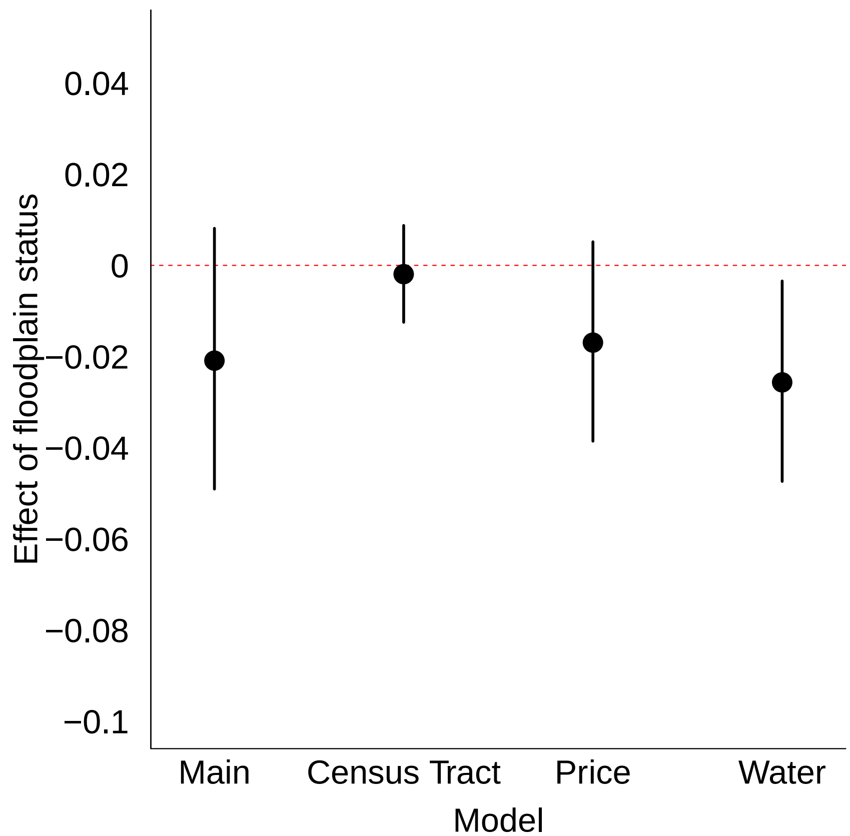

Figure S3: Panel regression results with alternative specifications. The main specification (n = 5.65M) on the left-hand side adjusts for the property, county-by-year, and age of the property at the time of sale. The "Census Tract" specification (n = 1.70M) limits the sample to only properties within census tracts with treated properties, and it replaces the county-by-year fixed effects with census tract-by-year fixed effects. The "Price" specification (n = 5.65M) returns to the main specification, but adds adjustments for price quintile-by-year, in case higher-value properties trend differently than lower-value properties. Finally, the "Water" specification (n = 5.65M) adds adjustments for distance to river-by-year, distance to coast-by-year, and distance to lake-by-year to the main specification. These allow for houses at different distances to water to trend differently over time.

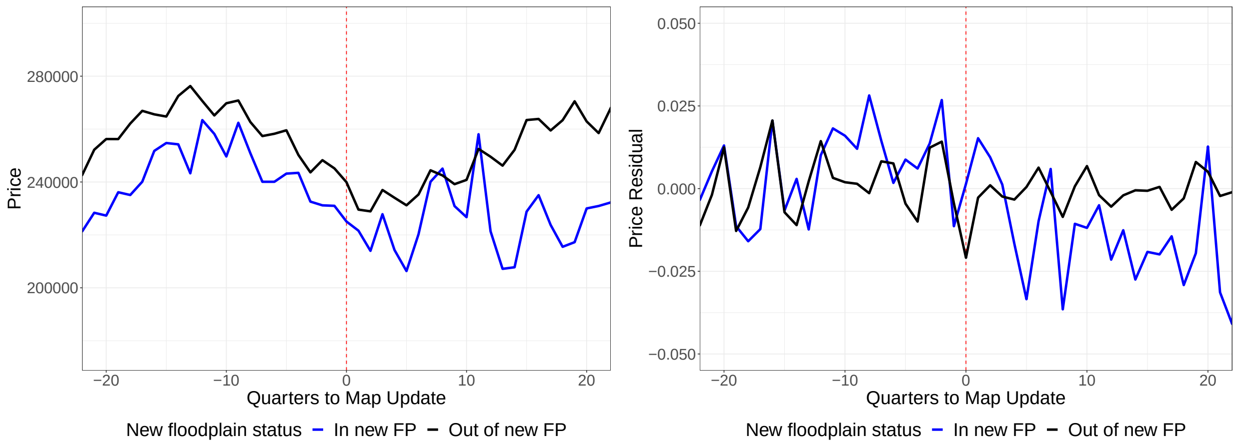

Figure S4: Pre-treatment prices of the control and treatment groups trend similarly. (A) shows trends in price and (B) shows trends in price residual relative to the time of map update. The price residual is the residual of price regressed on county-by-year fixed effects and property characteristics.

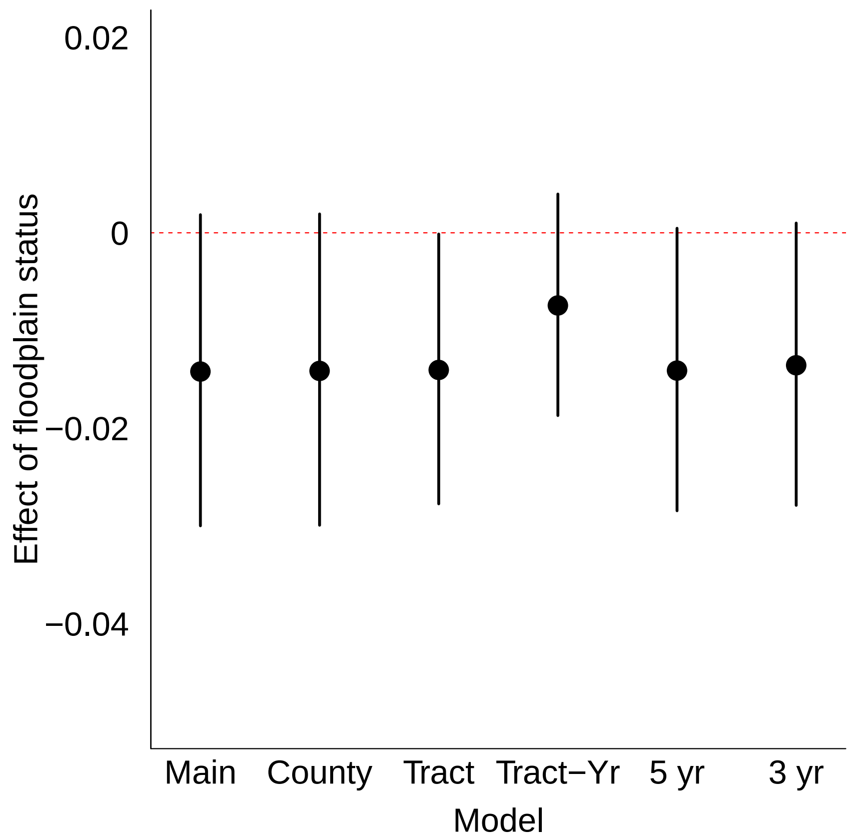

Figure S5: Difference-in-difference regression results with alternative specifications. The main specification on the left-hand side ($n = 5.64$M) adjusts for county-by-year time trends, the census tract, and the following property characteristics (all at the state level): number of baths, living area, land area, distance to river, distance to lake, distance to coast, distance to primary road, distance to secondary road, property age, and quarter of sale. The "County" ($n = 5.57$M) and "Tract" models ($n = 2.53$M) use the same regression, but remove properties that are not in the same county or tract as a treated property (that is, a property that is rezoned into the floodplain), such that the control properties are geographically proximate to the treated properties. The "Tract-Yr" specification ($n = 2.53$M) uses the same sample as the "Tract" model, but uses tract-by-year fixed effects rather than county-by-year. The "5-year" specification ($n = 3.4$M) uses only five years of sales on either side of the map update, and the "3-year" specification ($n = 2.23$M) only uses three years of sales on either side of the map update.

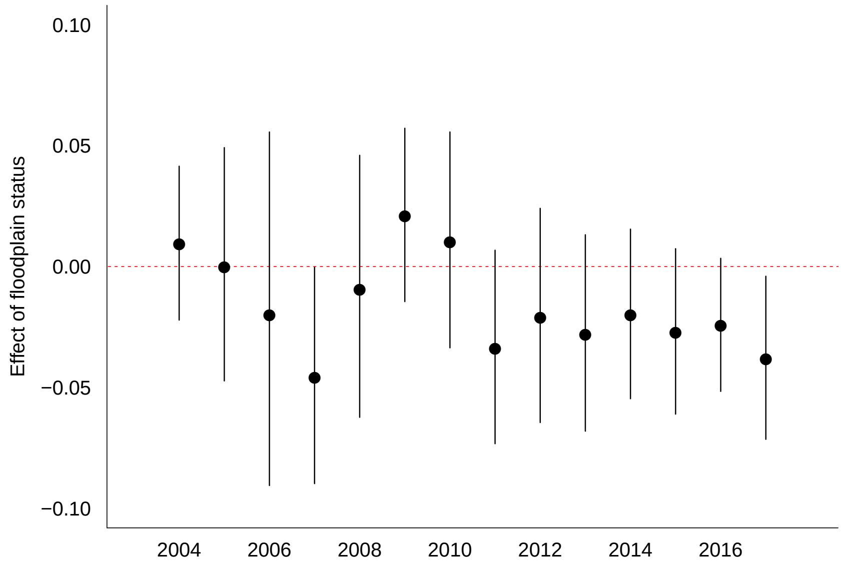

Figure S6: While policy changes in 2012 and 2014 phased out subsidies in NFIP pricing, estimates of the flood zone discount changed little. These results are generated using the main specification for the panel regression, interacting the floodplain variable with year (n = 5.65M). Because the number of treated properties increases over time (as more map updates occur across the country), only results for later years are shown.

Table S1: References included in Figure 1a. If references include information on average house and insurance prices, then they are also included in the rug plot in Figure 2, as marked at right.

References	In Fig. 2
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Table S2: Summary statistics of sales included in each of the three empirical approaches. Sales are grouped by location in current floodplain.

	Non-floodplain	Floodplain
Panel regression		
Sales	5,592,881	58,639
Price	254,244	262,782
Effective Year Built	1988.30	1987.20
Share within 1km of river	0.12	0.20
Share within 1km of lake	0.65	0.55
Share within 1km of coast	0.03	0.12
Difference-in-difference regression		
Sales	5,580,800	60,517
Price	247,808	229,115
Effective year built	1990.26	1989.45
Living area (sq ft)	1917.42	1811.71
Baths	2.44	2.25
Share within 1km of river	0.12	0.18
Share within 1km of lake	0.65	0.55
Share within 1km of coast	0.02	0.10
Cross-sectional regression		
Sales	16,815,678	802,207
Price	247,309	268,798
Effective year built	1991.16	1989.85
Living area (sq ft)	1980.73	1856.17
Baths	2.51	2.29
Share within 1km of river	0.11	0.25
Share within 1km of lake	0.67	0.57
Share within 1km of coast	0.02	0.25